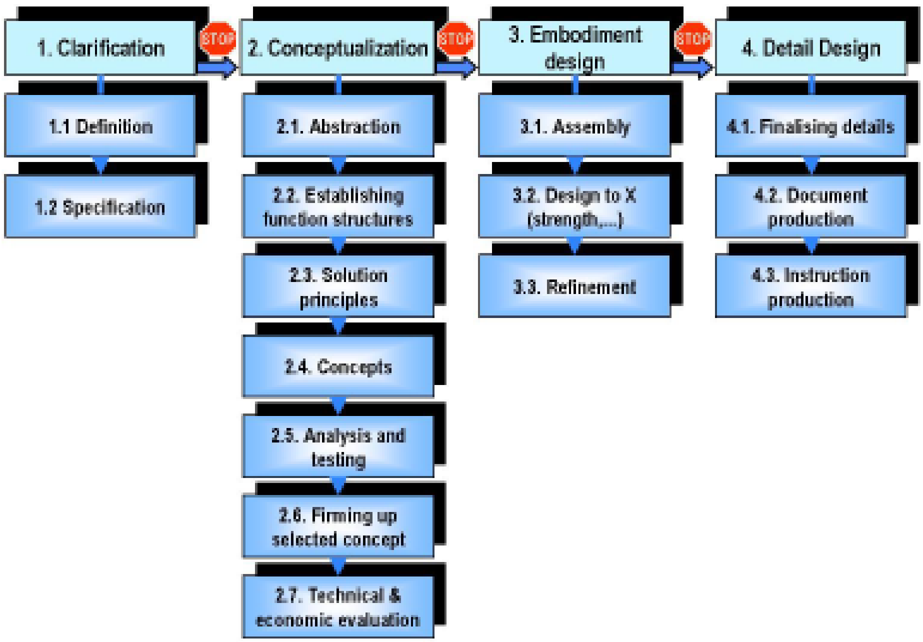
Virtual prototyping

VTT Research Programme 1998–2000



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Preface

This publication documents the papers to be presented at the Virtual prototyping seminar on 1.2.2001 at Otaniemi Espoo. The seminar presents the main results of Virtual prototyping research programme (1998–2000) of the Technical Research Centre of Finland VTT. Research program was entirely funded by VTT.

A virtual prototype is a computer model of a product in which all properties and information are included. The design, operability, production and testing of mechanical attributes can be conducted virtually before the product exists physically. Virtual prototyping aids e.g. the evaluation of mechanical properties and functionality, manufacturing planning, visualization and also ergonomy and safety design.

The aim of the research program was to increase the knowledge of virtual prototyping and also to create a firm contact network between different research areas within VTT using virtual prototyping technology.

The research programme included two main research projects. In the research project 'Integrated simulation based design', the aim was to develop an integrated simulation based design system which combines the design, manufacturing and use of a product in virtual environment. The design system is then applied to the analysis of mechanics design, manufacturing planning and to the real time simulation of operation. The most important issue is to be able to model the product so that the physical properties resemble the reality. A human dynamic model will be used as a part of the simulation system in designing ergonomy and safety.

The goal of 'Virtual Integrated Product and Production Development'-research project was creation of integrated product process to accelerate the whole development process from concept to production launch using virtual production tools currently available at VTT Manufacturing Technology.

Espoo, January 2001 Mikko Lehtonen

Contents

Concurrent engineering - organisational and software requirements

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Abstract

Integrated simulation based design requires effective methods to gain all desired results. Concurrent engineering is a product development method, which integrates all the company's functions. It brings together people, departments, software and many other functions so that their co-operation will work effectively. Integrating all the functions requires a lot both management and software. Management includes a new strategy, personnel training and commitment, teamwork, project management, communication etc. Secondly concurrent engineering method is useless without effective software integration in design and management. Also use of simulation and other information systems is essential.

In the future the global markets and new software will force the companies to develop their product development systems faster and better. Therefore it is necessity for the companies to implement concurrent engineering method.

1. Introduction to concurrent engineering

What is concurrent engineering? Definitions, explanations and opinions vary a lot in different countries and also many people disagree about it. Concurrent engineering (CE) has not an official definition, but here are three examples.

"Concurrent engineering is getting the right people together at the right time to identify and resolve design problems. Concurrent engineering is designing for assembly, availability, cost, customer satisfaction, maintainability, manageability, manufacturability, operability, performance, quality, risk, safety, schedule, social acceptability, and all other attributes of the product." (Dean and Unal, 1992)

"Concurrent Engineering is (Cleetus, 1992):
1. a systematic approach
2. to the integrated, concurrent development of a product and its related processes
3. that emphasizes response to customer expectations
4. and embodies team values of cooperation, trust, and sharing
5. in such a manner that decision making proceeds with large intervals of parallel working
6. by all lifecycle perspectives
7. synchronized by comparatively brief exchanges to produce consensus."

"the process of forming and supporting multifunctional teams that set product and process parameters early in the design phase." (Jagannathan *et al.*, 1991)

As it can be seen from previous definitions, people use different words and phrases, but they all talk about the same thing. The definition itself is not important but the understanding of the idea and effective use of the method.

Concurrent engineering method has many advantages compared to the traditional linear method, for example
1. Concurrent method instead of linear, the problems will arise earlier than before and they can be fixed before they are too big.
2. People can learn more in teams and workgroups. It is possible to see the big picture and understand interdependence between different departments.
3. Less engineering changes in the end phase of the design, so the development work is faster and cheaper. Time-to-market can be reduced.
4. Customer requirements are built in to the design from the start. Product will be in market at the right time and for the right cost.

In concurrent engineering the important issue is that all partners and departments use their own arguments in every phase: industrial design (what it looks like?), design (how it will work?), manufacturing (how to manufacture it ?), marketing (what the customer wants?), administration (how much it will cost?, how much profit it will make?), etc. In the beginning all departments bring out their opinions and wishes. In the planning phase there should be involved all the people who will use the product during its life cycle. Previous "over-the-wall" -method is no longer effective. Different values and criteria must be used. If some attribute improves, some other may be weakened, different attributes can contradict or be exclusionary. The result is always a compromise. When the work has started, the connections, monitoring, information control, communication etc. are essential and various design methods and techniques will be used. Trust and co-operation are very important in the concurrent engineering. All design teams need access to the data in early phase of the design (early involvement).

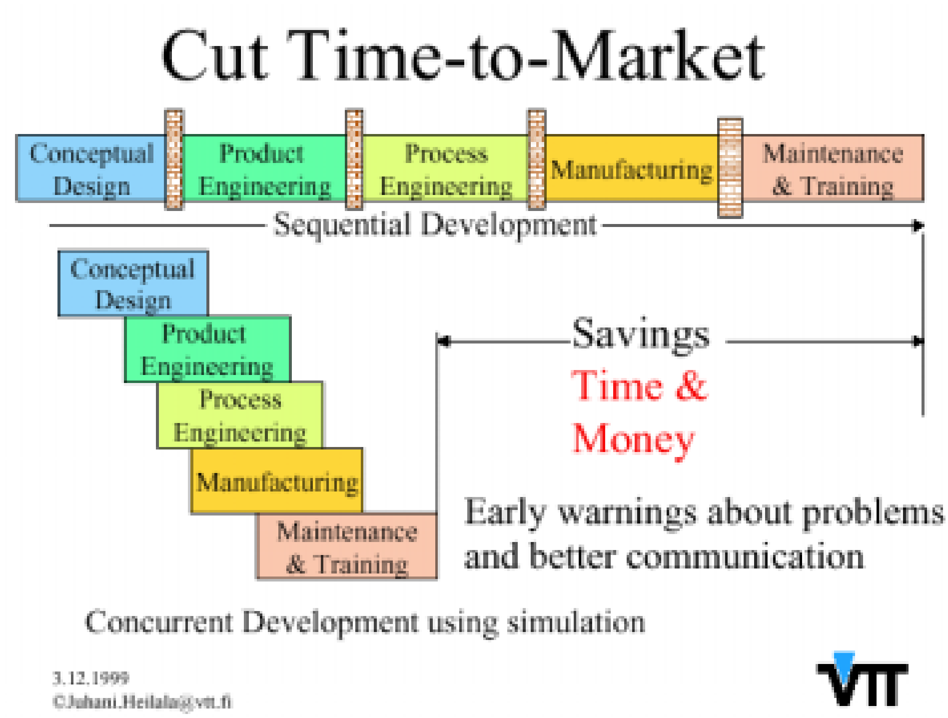

Figure 1. Overlapping in concurrent engineering.

Figure 1 describes overlapping in the concurrent engineering compared to the traditional linear method. Simulation is also mentioned in the figure, it is not possible to gain all the advantages of CE without effective software tools. In addition of the software also planning and design methods are needed.

Design methods and product life cycle

An effective use of concurrent engineering requires many planning methods. Those methods are often called Design For -techniques. The most familiar of them is Design For Assembly (DFA), but there are dozens of different methods for many planning phases. There are also many other methods e.g. Taguchi and QFD (Quality Function Deployment). Standardised methods will help design integration especially with other companies in the global markets. In concurrent engineering it is essential to think of all possible situations and phases of the product life cycle. Use of experts in every design phase of the products life cycle helps to consider all possible situations the product can have.

The product life cycle can be divided in many phases, like the following list.
1. Preliminary ideas
2. Definition of demands
3. Concept design (product)
4. Detail design (product)
5. Concept design of manufacturing system
6. Process design
7. Manufacturing
8. Assembly
9. Prototype
10. Sales & marketing
11. Installation, implementation, training
12. Normal use
13. Maintenance, repair, support
14. Disposal, recycling

In the future it will be more and more important to think of all possible situations during the product life cycle. To gain all the benefits of the CE it is important to have organisational factor in order, especially managers must understand and internalise the new operations model.

2. Organisation

2.1 Management and leadership

Many things have to be taken account when implementing CE in an organisation. Concurrent engineering demands a lot both managers and personnel. A decision to start using CE is a strategic decision in a top level of the company, both business processes and production processes have to be re-engineered. Implementing CE in an organisation is a long and difficult project but it is worth it. In an organisation it is useful to discuss about changes in people's roles. What new skills CE demands from people? The most important thing is an attitude change! An old way of thinking is not enough, personal view has to be changed to a wide organisational view.

Every organisation has to think about and answer the following questions.

- What kind of skills the managers need?
- What kind of skills the designers need?
- What kind of skills the employees need?
- What kind of attitude-, authority- and responsibility changes will occur?
- What kind of problems the changes can cause?

Important skills in concurrent engineering for both managers and personnel are team work, problem solving skills, communication, information technology, brainstorming etc., CAD/CAM, Quality Function Deployment, information/ process modelling, etc. All these skills have to work in an organisation.

Implementing CE in an organisation requires many phases

1. The new way of thinking, management commitment and personnel training
2. Analyse of present operations' models
3. Development of the new operations' models
4. Implementation of the software tools.

As it can be seen in a previous list, the first phase is an organisational change. Without top managers commitment it is useless to implement new methods or software. Authority and responsibility have to be balanced in every department and team, an old hierarchical organisation will not work properly any more.

Project management is more important than before. In concurrent engineering there is no time to make big mistakes, because all the phases effect to each other. Project controllability, manageability and scheduling are essential and it requires qualified project leaders. No one can do the work alone, it is essential to communicate with each other effectively if you are going to manage the whole project.

2.2 Communication and data management

Nowadays there are many methods to communicate with each other, both traditional and telecommunication methods. Every method has its benefits and disadvantages but the main thing is to control the data and its distribution in a proper and easy way.

In Table 1 there are some benefits and disadvantages of some communication methods. It is necessary to agree on which method to use in a project.

It is essential to control all the project data and therefore the project team must think about and synchronise the following

- Data acquisition and data transfer between design teams and software
- Data compatibility and timing, concurrent and real-time use of software
- Data distribution: public vs. classified information, access rights, data correctness and integrity.

Data management interfaces should be simple and easy to use. Nowadays intranet and extranet pages are effective way to distribute data to all partners. Most companies have traditionally many design and management software but concurrent engineering requires effective integration of the software.

Table 1. Possible benefits and disadvantages of communication methods.

	Benefit	**Disadvantage**
E-mail	+ it is possible to reply whenever you have the time + private	- difficult to know if the recipient has read the message - it is possible to send the email to a wrong address
Discussion group	+ many people can attend + it is possible to trace a large discussion	-some people do not read the messages - some people are afraid to write their opinions in a public group
Phone	+ accessibility is good with cell phones + easy and fast	- it is necessary to write down decisions separately - possibility to misunderstand
Fax	+ official + it is easy to write and draw many things easily	- slow, especially with large amount of data
WWW-page	+ a good place to store data + easy to manage and find a large amount of data	- some people do not read WWW-pages - regular maintenance is necessary
Personal meeting	+ effective communication + it is possible to make acquaintance + it is possible to learn to know a person	- travelling - it is necessary to write a memo separately

3. Software integration

During product development process there are various software used in a company. To gain all the benefits of concurrent engineering the design data must be integrated. Examples of software that are used in simulation based design (both design and management) are

- Computer Aided Design (CAD)
- Computer Aided Manufacturing (CAM)
- Production system simulation
- Enterprise Resource Planning (ERP)
- Product Data Management
- Email
- Project management software
- Etc.

All of this software generates a lot of data that must be controlled. The same data can be used in various software and by many people. Software integration helps to manage data transfer and use. Naturally it must be considered if the software integration is necessary, sometimes separate software will work fine if the project and data management interfaces are in order. Some software is almost impossible to integrate, so every case has to be thought separately.

In the future many software companies will produce integrated software including options for many design phases. The result of the trend is divaricate, when using totally integrated software data management and distribution are easy. On the other hand, the total cost for all necessary options can be too high or the software does not work properly with other vendors' products. In any case it must be remembered that software integration is the last phase when implementing concurrent engineering! Organisational changes and personnel training must be in order before taking use the new data management systems.

In Table 2 there are some benefits and problems of integrated software, beforehand it is almost impossible to know if the software works properly, so testing various software in advance is recommended.

Table 2. Possible benefits and problems of integrated software.

Benefits	Problems
+ data transfer is fast, easy and reliable + communication and understanding between partners is better + co-operation is easier, because it is possible to concentrate on relevant issues + it is possible to use the same data in various applications	- integrating separate software can cause compatibility problems - the system can be in separate pieces, so the data management is often imperfect - system/software must be adapted to the company. Just technological quality is not enough. - software integration is often slow and expensive, also maintaining cost can be high

Traditionally concurrent engineering has been used in manufacturing industry, but its ideas can also be used in other organisations. Previously mentioned organisational and software requirements does not differ much from industry to a research organisation.

4. Concurrent engineering in VTT

VTT (Technical Research Centre of Finland) is an expert organisation and research institute, so its operations are quite different from the private sector companies. However, also in VTT's projects concurrent engineering is a useful method. VTT's and the customer's co-operation can be organised so that all the new methods can be used effectively. There is nothing wrong neither VTT nor the customer, but the operations models and objectives are different.

Therefore the following issues have to be checked out when starting a new project between VTT and the customer

1. Interface between VTT and the customer. VTT and the customer have different operations methods so it is necessary to agree on how to communicate and work together.
2. Starting meeting. During the first project meeting it is essential to agree on many things: communication, commitment on both VTT and the customer, project plan, etc.
3. Preliminary information. What kind of material both partners need to start a project? In which format the data will be distributed?

When these issues have been agreed on, it is easier to start actual project work with a customer. Even if VTT's internal operations and projects differ from manufacturing industry, in the mutual projects concurrent engineering methods can be very useful.

5. Conclusions

Concurrent engineering is an effective method to use when organisational and software requirements are in order. Especially in simulation based design it is essential to use modern techniques because it is impossible to control all the data with traditional methods.

Concurrent engineering and the new technological possibilities will also considerable change the role of the engineers in the future. Software integration will continue, use of simulation will increase and the market globalisation will continue. In the future software will have more automatic functions, artificial intelligence etc. Therefore all organisations should implement simulation based design with concurrent engineering.

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Product data portal

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Abstract

A software system for supporting systematic design activities has been produced. The resulting system is aimed to provide a logical progression of design steps that should be carried out within a particular design domain. The purpose of the system is to support a concurrent design project with a dispersed design team. The present software is generic so it can be applied to a wide variety of design domains. In this paper, the system is described and examples of its use are presented. It is anticipated that the system provides the basis for managing the design process.

1. Introduction

The activity of design is often a complex and time-demanding process. Prior to the advent of computer-aided design, and increasingly with its development, many techniques and tools have been devised to assist the designer, to reduce lead times, to reduce errors and to minimize costs (Anuar & Atkinson 2000).

The techniques and tools are isolated however, i.e., unintegrated units. PDM (Product Data Management) systems are making things better, but their focus and scope is more or less targeted at document handling. Large PDM systems also include the concept of workflow inside the PDM. Workflow manages the predetermined business processes and consequently supports teamwork and adherence to business rules and practices. Such PDM systems, however, are unattainable for small and medium size companies because of the need for a large invesment in software, hardware and maintenance.

A system that could have the same useability and a predetermined design process flow methodology at a fraction of the cost of large-scale PDM systems was seen as an important goal. The constraints were that the basic useability of the system requires a browser (e.g., Netscape or Internet Explorer) and an office package that includes word-processing, spreadsheet, and graphics.

Therefore, the main challenge was to study the appropriate design methodologies that form basic design activities. It was seen as a good starting point to use some methodology because the implementation of the system becomes easier when it is based on design theory. The design methodology used by the system is not rigid, but configurable to meet a company's special needs.

The main objective was to produce a software system that embodies a systematic methodology for producing a logical sequence of design procedures.

2. Previous work

There are many books and papers which deal with systematic design in the mechanical engineering field (e.g., Cross 1989, Hundal 1990, Eder 1990, Yoshikawa 1982, Takeda *et al*. 1990, Roozenburg & Cross 1991 and references therein). The systematic design methods are usually based on particular views about the design process. The views are derived empirically from the authors' long experience in design activity.

Usually these design theories are divided into two different groups, according to the main principles and linguistic area. The first category includes the design theories that are of an algorithmic type, and come from the German-speaking area (Central Europe), and the other category the informal type coming from the English-speaking area (UK and USA). Here, we do not discuss the "English models".

On systematic design methods

Over the past several years, researchers have sought to characterize the design process with different models and formulate it with systematic design methods (Pahl & Beitz 1984, Hubka 1987, Roth 1981, Tjalve 1979, VDI 2222 1987). These methods describe or prescribe how the design process should be performed. Systematic methods aim to increase the efficiency of the design process. Systematic design methods describe the design process as a sequence of phases, of which there are usually four.

According to the design method described in Pahl & Beitz (Pahl & Beitz 1984, p. 41), the design process has the following phases:

- clarification of the task
- conceptual design
- embodiment design
- detail design

Clarification of the task involves the collection of information on the requirements to be included in the solution and information on the constraints. The clarification of the task results in the specifications of the product to be designed (the requirement list). The conceptual design phase involves the establishment of function structures, the search for suitable solution principles, and their combination into concept variants.

In the embodiment design phase, the selected concept is worked out in layouts and forms. The general arrangement and spatial compatibility, component shapes and preliminary material selection, and production plan is determined. In the detailed design phase of the design process, the arrangement, form, dimensions and surface properties of all the individual parts are finally laid out, the material specified and all the drawings and other documents produced.

Next, for comparison, we present schematic representations of the systematic design methods by Pahl & Beitz, VDI 2222 and Roth (Table 1). The different phases of Pahl & Beitz and VDI 2222 resemble each other as well as the nomenclature. Roth emphasizes the form design phase (form = structure of the product and shape of the components). Also, he highlights the use of solution catalogues. He addresses the design process as an algorithmic design method by means of classified design catalogues (Algorithmischen Auswahlverfahren zur Konstruktion mit Katalogen).

Table 1. Classification of three systematic design methods (Pahl & Beitz 1984, VDI 2222 1987, Roth 1981).

Pahl & Beitz	**VDI 2222**	**Roth**	**Phase**
Clarification of the task	Clarification of the task	Clarification of the task	clarification of the task
Requirement list	Requirement list	Requirement list	
Conceptual design	Conceptual design	Functional design	conceptual design
Function structures	Main function and subfunctions	General function structures	
Principle solutions	Varying, combining	Physical-Logical function structures	
Evaluation	Evaluation		
Embodiment design	Embodiment design	Form design	embodiment design
Preliminary form	Dimensioned form	Structure	
Detailed form	Evaluation	Shape	
Final form	Optimizing	Evaluation	
Detail design	Detail design	Design for production	detail design
Complete detail drawings and production documents	Complete detail drawings and production documents	Complete production documents	

Conflicting opinions for these general systematic design methods are suggested by Krause *et al.*, who indicate that product-oriented design methods should be developed, as present design methodologies are much too abstract in practice. Abstract design methodology describes abstract design procedures but "tests in practice have shown that designers prefer individual methods, which are related to the product and to production" (Krause *et al*. 1991, p. 1012).

3. The used design methodology

The design process methodoly to be used in the portal was chosen to be based on VDI 2222, with additions according to the project carried out at VTT 1994 (customer oriented product design, pre-study, Asiakaslähtöinen tuotekehitys, esitutkimus). The design process is controlled with the user-interface, in which a desired sequence of design events is predetermined, but configurable.

- A clarification phase that facilitates the user to enter the descriptions of design requirements and design factors.
- A conceptual phase involves the establishment of function structures, the search for suitable solution principles and their combination into concept variants.
- An embodiment phase involves the determination of the layout and shape.
- A detail design phase determines arrangement, final form, dimensions and surface properties of all individual parts. Materials are specified, the technical and economic feasibility re-checked, and all final assemblies and production models are produced.

4. Software architecture

The initial idea of the system was to be able to use it only with a browser. The two leading browsers (Netscape& Internet Explorer) were tested.

The underlying directory structure (Fig. 1) is adjustable to each company's, or networked companies' needs.

How to add projects

Every new project is created according to a basic template. There may be different templates for different kind of projects. Template includes the structure of the methodology and hyper-links that bind the system components together, and also documents that belong to a certain design task.

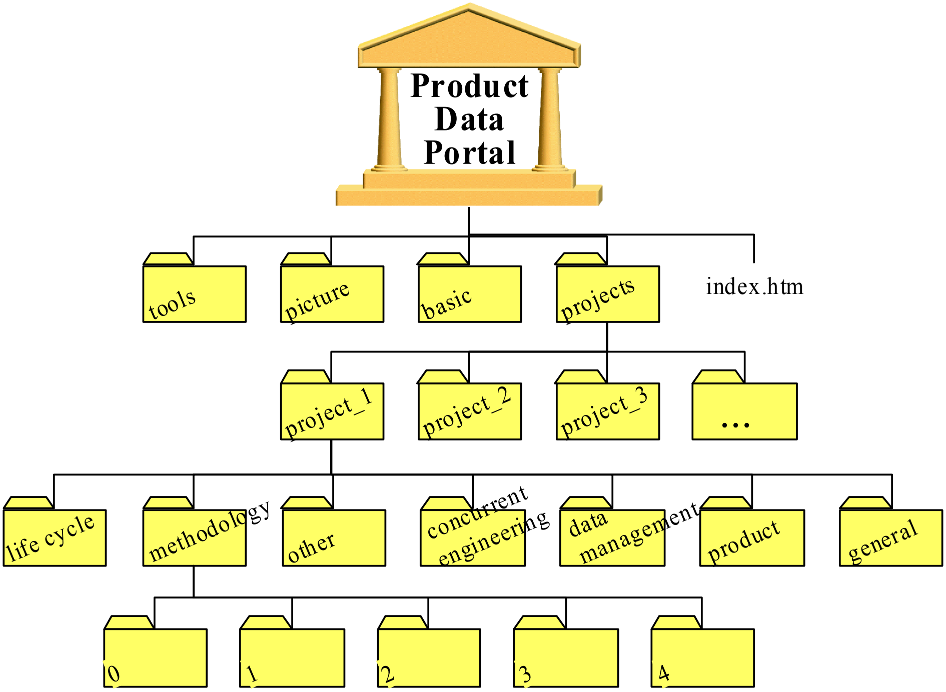

Figure 1. Directory structure of the product data portal. Every project has the same upper-level structure and sub-directories are created according to the appropriate template.

Tool integration

Different software tools, CAD, FEM, Visualizers etc., are not necessarily integrated into each portal station. There may be different tools for designers and analyzers. Some stations may manage only with a browser, i.e., viewing capabilities are enough. Tools to be implemented are adapted to demands of the users.

Technically, tools can be installed in each workstation or they may be used over the Internet. At the moment, there are a few pure Internet-based design and analysis tools, but we may not have to wait long for more. As a hybrid solution, there are tools that require basic installation to a workstation and thereafter the software starts up when connecting to an Internet server. The CAD software, Alibre (www.alibre.com), is an example of using web-based technology to manage worldwide data management and collaboration.

5. Use of the system

First, the user connects to a certain Internet site, e.g., http://proxnet.vtt.fi/PROJEKTI. Secondly, the user logs on (Fig. 2), and the selected choice of projects are displayed according to access rights (Fig. 3).

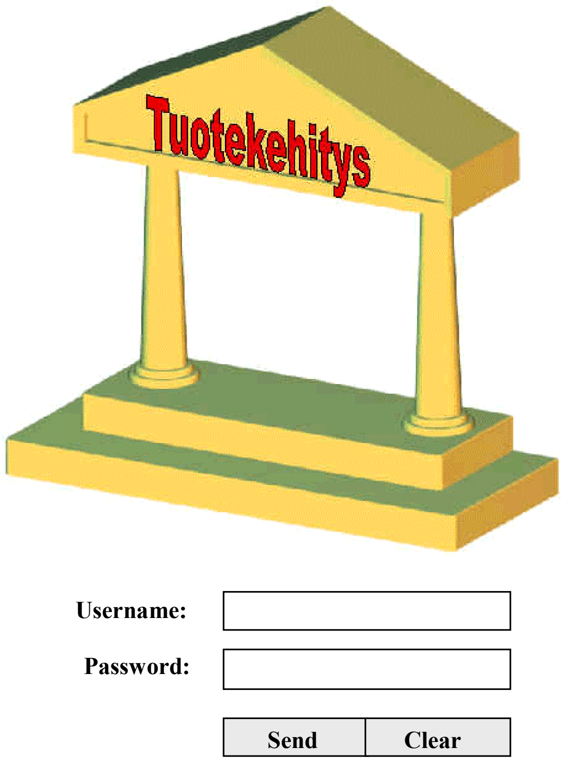

Figure 2. User-interface to log onto the system.

The main page opens, showing the functionality of the system. The user-interface is customisable for each project's needs. Figure 4 shows the main page of the system.

Figure 3. The user selects the project by clicking the mouse. The allowed projects are shown on the screen.

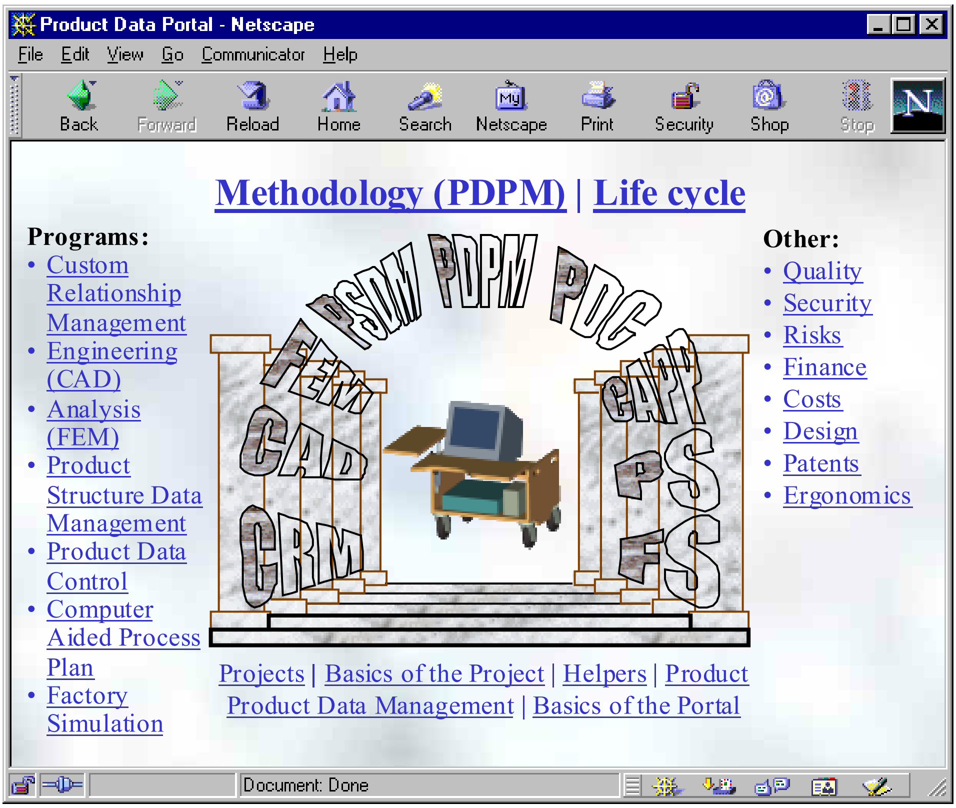

Figure 4. The main page of the system.

Methodology

The methodology of the system is based on VDI 2222. It is built-in so that the user starts the methodology by clicking the word Methodology. Figure 5 shows the main page of the methodology. There are four main phases as in VDI 2222. All of the documentation for every project is divided into four main parts: clarification of the task, conceptual design, embodiment design, and detail design. In Figure 6 the conceptual design phase is selected, specifically task 2.6. It shows the sub-tasks and clicking to a certain task opens the associated document.

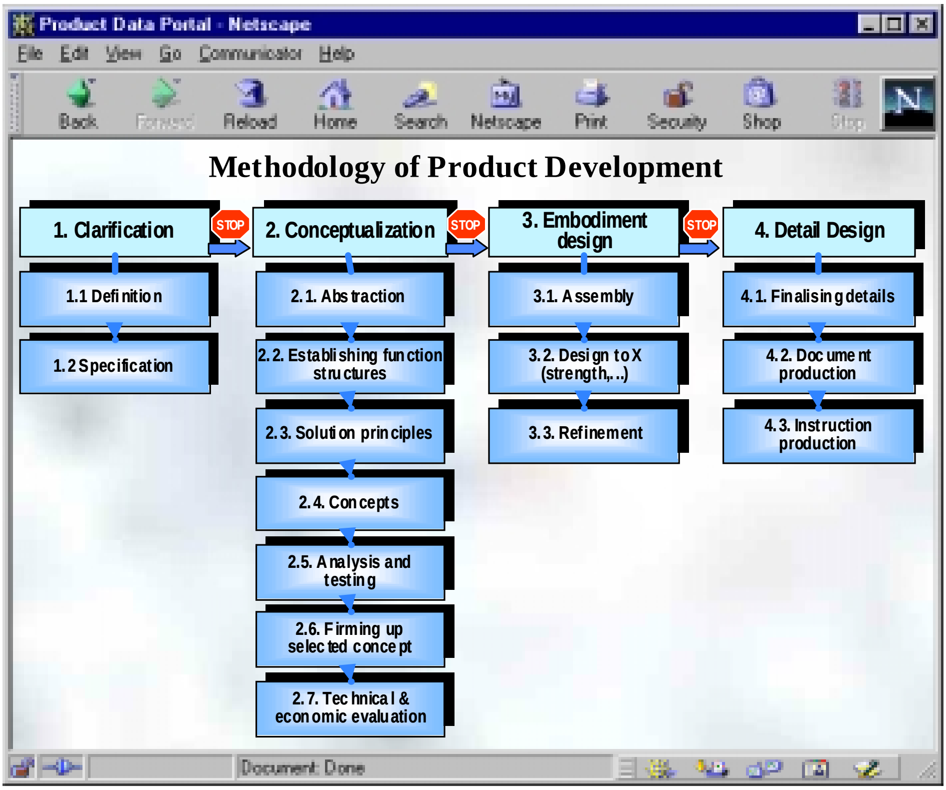

Figure 5. View of the methodology page. The design process structure is shown on the screen. The graphical view to the process assists the user to manage different design tasks. The user clicks a design task and a view of sub-tasks is opened.

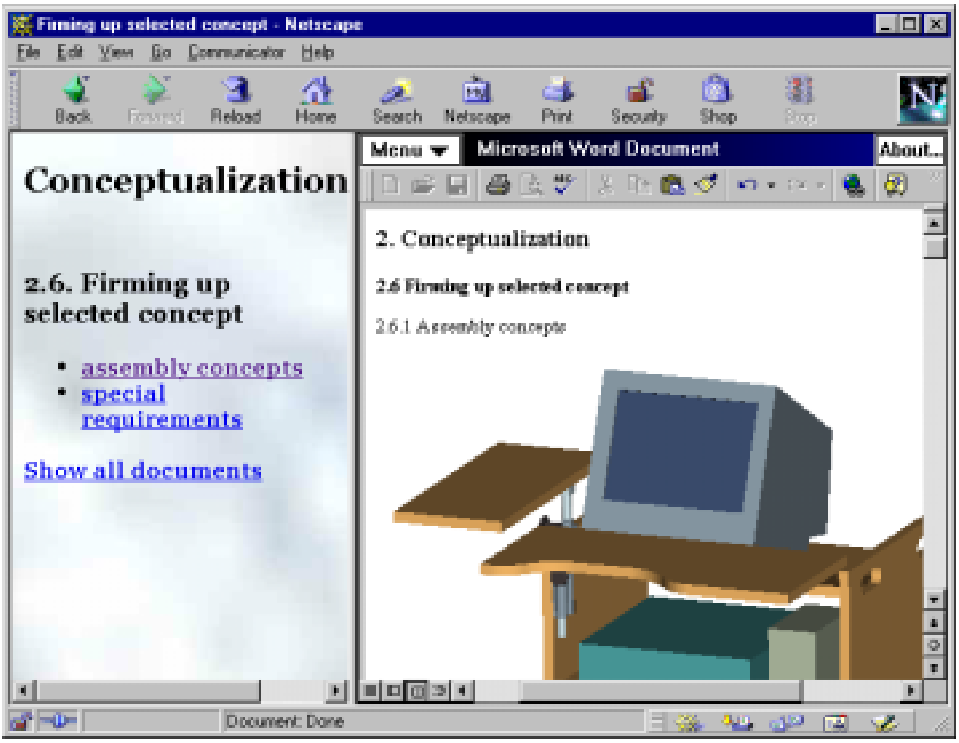

Figure 6. View of the document handling. On the left side is shown the navigation frame. The frame on the right shows the associated document or list of all documents that belongs to the current design task.

6. Discussion

The feedback suggests that the system is easy to use and the given instructions are reasonably easy to understand. Some comments were made about the difficulty of understanding the terminology. It is acknowledged that this was due to lack of a user guide and on-line help, which should provide the required explanations. The system has not been tested in a real life environment so there are some issues to be clarified. These include:

- the layout of the hyper-links
- learning time
- results produced by the system

7. Conclusions

It is clear that, in a concurrent engineering environment, some or many design activities must happen simultaneously. If these tasks can be planned, then much valuable design time and effort may be saved. It was shown that a product development support system could be implemented using basic information technology. This means that small and medium size companies can buy a system at a fraction of the price of a comparable large PDM system.

The true power of the technique will be in the design projects, where collaborating features play an important role.

Acknowledgements

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Real time simulation in product development

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Abstract

At the same time as structural stress calculations in steady state situations become more complex and more accurate also simulation of the temporal behaviour of design details is developing quickly. Through advanced integrated design tools simulation studies will soon becoming everyday practice. But simulation techniques have a much greater potential than this. The vision is that the complete design can be simulated accurately enough to produce what is being referred to as a virtual prototype. Because variations to the design can be reflected quickly in the model, virtual prototyping can be much more tightly integrated in an iterative design process. The concept is of special interest in the case of human-operated products and in areas of industry where full-scale physical prototypes are either risky to operate or too expensive to produce such as in the defence or shipping industries.

If a virtual prototype is to replace the physical prototype as a part of the design process, it must have the same dynamic behaviour, it must have a detailed and accurate visual representation and it must have a realistic user interface. In order to be a commercially attractive alternative it must also be quicker and, in the case of man-in-the-loop simulations, the user must be assured that the person involved behaves as in reality. The computer hardware to produce such simulations already exists. Currently available computing capacity and 3D performance are not the limiting factors. The bottleneck is still on the software side. Although new software emerge continuously much remains to be done before compatibility issues, software features, robustness of applications etc have reached a level when off-the-shelf products can play a part in building commercial virtual prototypes for real-time simulation.

In this project some currently available software packages and future trends in modelling dynamic behaviour were studied. The focus has been on interactive real-time simulation of land vehicles to support virtual prototyping. It appears that the products available today still have a long way to go with regard to flexibility and ease of use. Recognised and widely used software such as ADAMS still lack the features needed for real time simulation. It is evident that market is quickly developing and that products used today may be outdated tomorrow while at the same time totally new products emerge. A strong trend is the integration of existing, well-established products into powerful integrated design and simulation environments. All this forces users to keep a view on the market and avoid locking their positions to single provider solutions that restrict migration to other products in the future.

1. Background

Computer based design is advancing quickly towards increasingly complex products. In addition to the design of the product itself, digital technology is extending to cover all stages of the product development from initial design to production planning. Numerical methods are used for stress calculations and mechanisms can be studied visually in kinematics simulations. These different tasks are being integrated in large stand-alone software packages and compatibility of specialised software is improving through co-operation between different software vendors. At the same time as applications develop they also become more widespread in industry including small and medium size enterprises.

The prerequisites for this development is, of course, the decreasing cost of computer capacity but especially the development of highly efficient graphics processors enabling the use of 3D modelling throughout the design process. Computer based product development is eventually showing its capabilities of reducing development costs and time to market.

In ISSU project we have studied how and using what tools it is possible to create functional virtual prototype from common 3D-design geometry. So that a real-time simulator could be done like a by-product during the product development process.

2. Simulation as part of the design process

Structural dimensioning often requires complex calculations of the structure's behaviour under different load conditions. Finite element methods are frequently used to solve steady state problems but also dynamic processes such as deformations in a crash test. Although involving extreme amounts of computation these methods are usually well mastered. The computation time involved in many numerical and analytical methods usually prevent these from being used in real-time simulations. However, regardless of how well these problems can be solved, the validity of the results eventually depends on how well the stresses and forces acting on the structure can be determined. This is true especially for various types of vehicles operated interactively in different modes and environments. In order to determine the forces on a vehicle in operated by a human requires an operational prototype.

Traditionally, the only way to test a design in operation has been to build a physical prototype. The process is both slow and costly. Changes to the design can have widespread effects on other parts of the chain, such as production methods and materials and may dramatically delay the planned time to market. Physical prototypes do not fit well into the concept of concurrent engineering.

In order to study forces acting on manually operated devices the other option is to simulate the full dynamic behaviour of the design including the interaction with the environment and with the user.

As part of the ISSU project we have studied current simulation tools, the compatibility between different design tools in use and the options for creating customised simulation applications to be used as a part of product development.

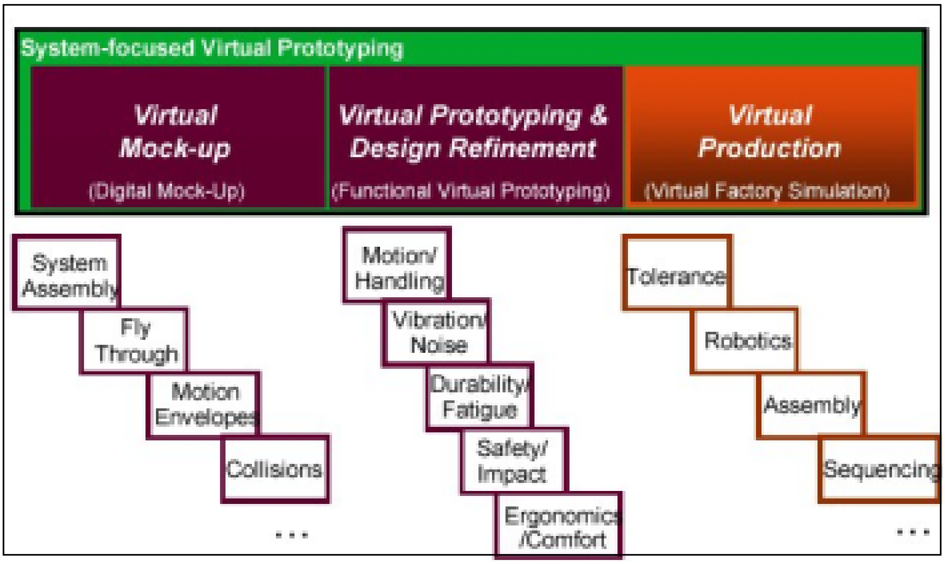

Figure 1. System oriented virtual prototyping as a part of product development. (By R. Ryan, MDI, 'Digital Testing in the Context of Digital Engineering'. ADAMS user Conf. 1999, Berlin.)

3. Tools and technologies

A number of tool options are available for creating interactive dynamic simulations of designed constructions. These range from computer coding using function libraries to fully integrated software packages. Typically dedicated software environments aim at higher productivity and reliability of results but may have restrictions on the application areas. Lower level coding give more flexibility but also increase the work required.

With integrated simulation packages you can model the geometry, create the kinematics, define the constraints and dynamics, perform simulations and finally analyse the results. This type of software packages are usually specialised to meet some particular simulation need e.g. robot simulation. Although the packages usually have a geometry modelling option the preferred way may be to use dedicated modelling software and import the 3D models to the simulation environment. Especially if 3D CAD designs are available the use of these in simulation visualisation seems sensible. Thus, the number of model file formats supported and the quality of file import and file conversion functions become more important than the quality of built-in model creation tools. If CAD models created for other purposes are to be used a simplification with regard to the number of polygons used may be necessary if a real time visualisation is to be achieved.

Block-diagram modelling environments such as Simulink are open to different simulation needs. The simulation model is created graphically from different blocks that are picked from the library, usually special custom-made blocks can be done too. Although the user interface is still to a great extent graphical this provides a higher level of abstraction compared to geometry based modelling.

Strictly code based tools are e.g. function libraries and various code generators. These provide a high degree of flexibility but on the other hand require in depth knowledge of both the software and of the underlying physics. Due to the steep learning curve small tasks may take a relatively long time to complete if the user is inexperienced. Also the reliability of the results depend on the skills of the modeller.

There are currently many integrated simulation software packages on the market. The most known simulation tool for multibody dynamic systems is Mechanical Dynamics Incorporated's (MDI) ADAMS (Automated Dynamic Analysis of Mechanical Systems) which have many modules for different design categories e.g. engine, rail, controls, hydraulics etc. There are of course many other simulation tools too: PTC's Mechanica/Motion, LMS's DADS, MCS's Working Model, Samtech's Mechano Motion, Altair's Motion View and INTEC's SimPack to name a few. All of these programs are destined to simulate dynamical mechanic systems but none of them is capable for real-time use yet.

The trend is that 3D design tools will have more and more simulation features. Many of them already have capability to create kinematic systems but there are already some which have dynamic simulation properties too e.g. CAT/ADAMS. It can be seen that 3D, FEM and simulation programs will be networked to bigger assemblies in the near future.

ADAMS is also studied as it is pre-eminently famous in automotive industry and is used many years at VTT. Currently it is not capable of real-time use but after the computers become more powerful and the software develops it will be. We tried simple simulation model that was modelled in ADAMS and controlled by Simulink. And yet it was very simple it was not real-time.

Another tool that was evaluated in this project was Deneb's Envision. This program is originally targeting robotics and factory automation sectors and is well suited for creating virtual mock-ups using kinematics simulations. An option for dynamic simulation is available and the software has built-in support for real-time simulations. The dynamics features are, however, limited and not suited for simulating dynamical land vehicles. E.g. dynamics of collisions and automatic terrain following are missing.

4. Real-time simulator of a tractor – a demo case

To test the programs in a real life situation an interactive real-time simulation of a tractor was selected for a demo case. The same vehicle had already been studied in ADAMS and the 3D geometry was therefore already available and the construction was familiar. The purpose of this demo was to study how real-time simulator can be made, how the programs work together and what are the limitations of the current simulation software.

The purpose of a real-time simulation was to extend existing ADAMS simulations by introducing the human-in-the-loop. It is usually difficult to know the real strains that the product will experience during its use and how these strains change depending on the user. Another aspect is that the product and its functions can be tested, and maybe its use trained, in virtual environment before any physical prototype is made. It was accepted that the same level of realism and reliability might not be achievable in a real-time simulation because of the simplifications to the geometry. Also the numerical solvers must be optimised for speed instead of accuracy. If a realistic behaviour could be achieved another option is to use recorded operation sequences and study them in ADAMS.

The simulation was distributed between three separate computers communicating on a LAN. Each unit handles its specific task of input control, visualisation and calculations. (See figure 2) The tractor is steered via authentic steering device which is instrumented with potentiometers to track the positions of the steering wheel, gas pedal, brake pedals (left and right) and gear stick (forward, neutral and rearward). The analog input was measured using a standard AD input module and processed using LabView software. The processed data is passed using TCP/IP over the LAN to a calculation computer which uses MathEngine based C++ code to determine the dynamics of the tractor and transfers the orientation and position data to visualisation unit. WorldUp software is used to visualise the simulated view.

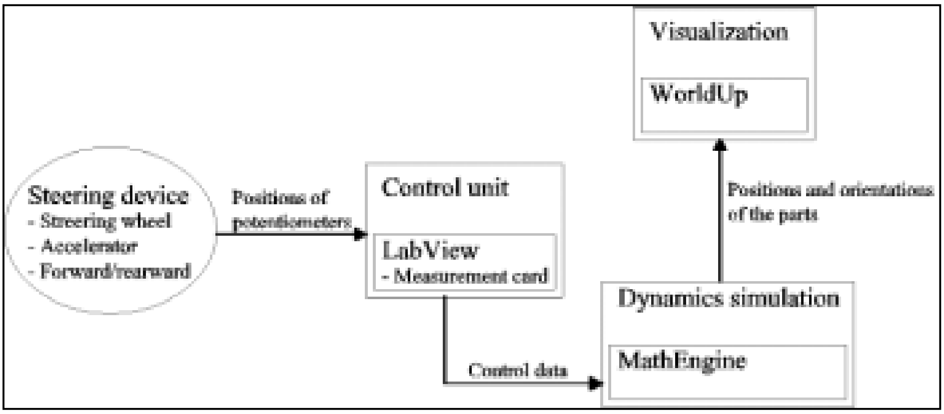

Figure 2. The structure of the tractor simulator.

MathEngine Dynamics Toolkit 2.0 and Collision Toolkit 1.0 were used as a simulation tools in this demo. These are C++ function libraries and suited to implement dynamic systems for engineering applications, virtual reality and computer game development.

Sense8's WorldUp (WUP) which is used as a visualisation tool is a software development environment for building 3D applications. WUP is object-oriented environment that contains predefined properties and methods that can be accessed via the development interface or through the Visual Basic-style scripting language.

The kinematics model of the tractor was created in the WUP by importing the geometries in IGES-format and then constructing the body parts to a complete tractor. In MathEngine the dynamic tractor model with all mass and inertia properties was also built. Visual Basic was used to program a communication application between WUP and MathEngine. The communications between the computers is handled with TCP/IP network.

5. Discussion

The use of virtual prototyping is quickly increasing in all phases of product development from visual mock-ups to production planning. In the automotive industry where human decisions greatly affect operational loads there is a need to use "human-in-the-loop" simulations. For the human involved to behave naturally the feedback from the system need to be realistic and accurate. Minimum requirements are a real-time simulation with high quality visuals and a user interface with the same ergonomics as the planned design. This usually means that some sort of hardware must also be integrated. Accurate calculations are still time-consuming which means that there will be a trade-off between accuracy and speed. To fulfil the requirement of a real-time interactive simulation faster and thus less accurate algorithms and numerical solvers must be used. A demanding task will be to weigh the benefits of the human-in-the-loop against the reduction of accuracy. In this process not only technical performance but also human behaviour must be measured and evaluated.

Most of the advanced simulation tools on the market today are not intended for real-time simulation. Using a mixture of tools and technologies on a case by case basis is usually not attractive for commercial companies. High productivity can best be achieved through thorough knowledge of a good design tool. There is no doubt that such simulation tools will be available in the near future.

Simulation and analysis of human machine system

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Abstract

The main objective of the research contribution presented in this paper was to enhance the usability of digital kinetic human models in the context of virtual prototyping and human-machine system simulation when the situation is dynamic. Main tasks were applying and evaluating two commercial digital human models, creating own digital kinetic human model, connecting ergonomic and safety analysis methods to system.

The goal of the VTT Automation's research contribution was to enhance the digital human model in the concurrent design context both in a direct contact with the machine manufacturer or using a product development portal as contact interface. This includes the development of participating team-based concurrent engineering and integration of digital human model to the human-machine simulation, too.

1. Introduction

In the conceptual phase of product development process the decision making has commonly based on incomplete or insecure information. However, the conceptual phase defines 80 % of the product costs and guides the baseline of detailing development process. Virtual prototyping solves many of these problems. This paper presents the research *'Human Model in Virtual Prototyping'* which was the research contribution of VTT Automation to VTT's *'Virtual Prototyping'* research program.

Virtual prototype has an accurate geometry and behaves like the real physical system. Virtual prototyping is a process to model, analyse, test, and develop a product prototype. Performance, manufacturebility and other properties of the product are tested by virtual means. The human behaviour, ergonomics, safety, and interactive behaviour of human-machine system can be tested and analysed by using digital human models and virtual prototyping.

2. Human Models and simulation

A bunch of different human models have been developed for different purposes. Kinematic human models are adequate for some cases e.g. workspace analysis. Kinetic or dynamic human models are needed to calculate loads. The level of details and degree of freedom depend on the simulated task, and so on.

The introduction of human motion into biomechanical models introduces two types of complexity. First, the motion must be described in a *kinematic* fashion. The second complexity regarding human motion biomechanics has to do with modelling the *kinetic* forces and moments of complex linkage systems during the motion. As a human motion is executed complex inertial forces are created by changes in the velocity and direction of the motion. These changes result in accelerations and decelerations of the various body segments, which, by the application of Newton's second law ($F=ma$), create inertial forces. (Chaffin *et al.*, 1999)

2.1 Human-machine System Simulation

Human-machine systems are separated into two main categories: active work such object manipulating and passive work such human sitting in moving vehicle. Real work tasks are normally combinations of those categories.

Passive simulation involves the human body's response to the physics of the environment. The applications in this area include crash, falls, impact, etc. Data received from these simulations include segment contact force, displacement, velocity and acceleration, joint force and torque, and may be compared against injury norms for evaluation of the potential harm of a physical event. Active simulation involves the human body becoming an active participant in the physics of the environment. There are a number of options to drive the motion of the human. (MDI, 2000)

Two common software packages, ENVISION and ADAMS, were chosen for test of dynamics simulation of human-machine system. Couple of commercial human models; ERGO and FIGURE Human Modeler were applied and tested (see chapter 2.1).

ENVISION is simulation tool for design, evaluation, and programming of robotic workcells. Robot kinematics and dynamics can be modelled and simulated easily in ENVISION but there are constraints on general dynamics simulation. There can be only one translational and one rotational degree of freedom on one part. This is adequate for robot kinematics but complicates for example vehicle dynamics modelling. On the other hand, dynamics simulation is optimised for robot type systems and computation is quite fast.

ADAMS (Automatic Dynamic Analysis of Mechanical System) is general multi-body system simulation software. It is versatile and for example hydraulics and controls can be simulated interactively with mechanics.

The hypothesis in this study was that ENVISION is the tool for active work task simulation and analysis whilst ADAMS suits passive task simulation.

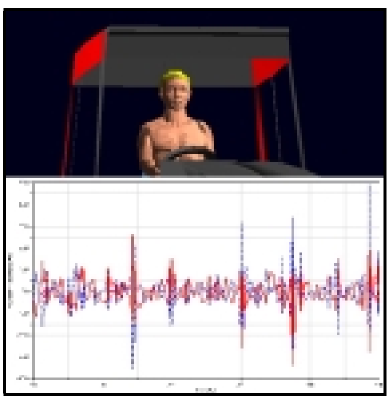

Figure 1. Human-vehicle system analysis with FIGURE Human Modeller and ADAMS.

2.2 Kinematic and Dynamic Model

The kinematic case can be used for evaluation of reach distances and space requirements. In the dynamic case the forces acting on the model arise from the environment, and the inverse dynamic case the user would prescribe a motion pattern and the system would calculate the necessary force and torque to obtain the prescribed movement (see chapter 2.1). (Nilsson *et al.*, 1992)

Table 1. Examples of commercial kinematic and kinetic or dynamic human models.

Kinematic human model	
ERGO, ERGOMan, SAFEWORK	Delmia inc.
Jack	Transom Technologies Inc.
Dynamic human model	
FIGURE Human Modeler	Mechanical Dynamics Inc.

Two commercial human models (ERGO and FIGURE Human Modeler) were assessed and evaluated in this project.

2.2.1 ERGO human model

scenarios. In ERGO™, human motion is rapidly prototyped or "captured" into the virtual environment, enabling quick and precise analysis of reach, lift, posture, cycle time, visibility and motion. Analysis capabilities include range of motion, NIOSH lifting guidelines, Garg energy expenditure, upper limb repetitive motion assessment, and Methods Time Measurement (MTM-UAS). (www.delmia.com)

Potentialities to simulate dynamics with ENVISON and ERGO human model were determined and possible problems and challenges were explored. The inverse kinematics of ERGO does not work in dynamics simulation. Several joints in human model have more than one degree of freedom. In ENVISON a part may have only one translational and rotational degree of freedom. This causes great problems. ERGO was dumped in this study because dynamics simulation demands tremendously modelling and programming.

Figure 2. Work task planning exploiting ERGO human model.

2.2.2 FIGURE Human Modeler

The FIGURE Human Modeler is an add-on to ADAMS/View. The human model created within ADAMS/View may be combined with any type of physical environment or system for full dynamical interaction. The human models may be created with a level of sophistication ranging from simple to very complex. They would address a wide range of applications from gait simulation to vehicle ride comfort.

The base level human models built in FIGURE are the fifteen segment, sixteen joint type. Included in FIGURE are the model files for all the bones in the human skeleton. The 15-segment body representation involves a grouping of these bones. At any time the human model may be displayed as ellipsoids, skeletal or as a skin/clothed model (Figure 3). Interaction with the environment or mechanical systems is described using automatically generated ellipsoid-flat surface contact elements.

The joints in the base human model are tri-axis hinge joints created at anatomical locations. Forces in the joints may be of the passive or active type (see chapter 2.1). A forward dynamics approach may be used where the user describes the angulation history of the particular degree-of-freedom and generates a torque using the automatically generated proportional-derivative (PD) controller. This angulation history may be imported from a data table or generated using an inverse-dynamics approach. If muscle forces are used, muscle elongation histories or activations may be used to drive the model using elongation histories generated from an inverse-dynamics simulation. (MDI, 2000)

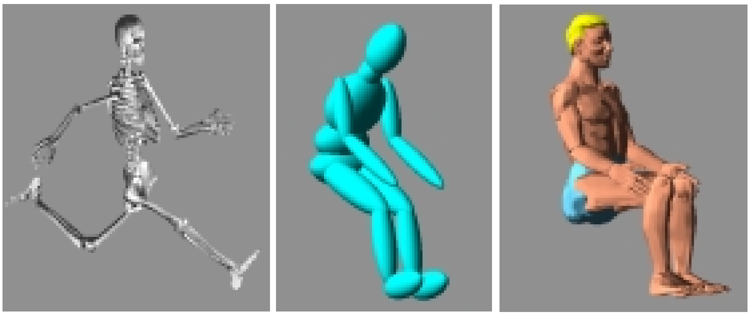

Figure 3. Human Model Display Choices: Skeletal, skin, and ellipsoid.

2.2.3 VTT Automation Kinetic Human Model

One objective in the project was to examine expedients to model human body and actions and to create own simple kinetic (dynamic) human model in ADAMS software. A fifteen-segment human model with hinge and spherical joints and torque vectors in joints was constructed. Torque functions contain controllers which aim to maintain certain posture in passive type of work task simulation. The model was tuned by comparing simulation results to FIGURE results.

Yet there are lots of things to enhance in the model human loads can be simulated with some accuracy by the current version of model. For example usability, user interface and analysis tools need enhancement. An external converter and analysis software was also created in the project (see chapter 4).

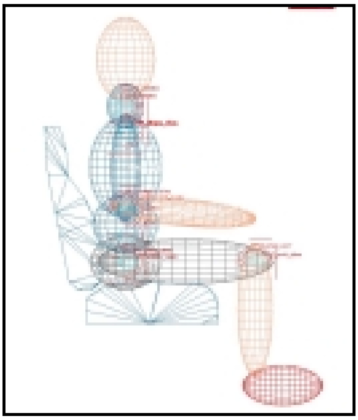

Figure 4. Exploiting VTT Automation human model in vehicle comfort analysis.

2.3 The function and utilisation of the motion capture system

Ascension MotionStar Wireless® is a motion capture system, which utilises magnetic tracker. The wireless data transmission system in the data suit is also attached to 5DT's 5th Glove '95 data gloves. In magnetic tracker, magnetic fields are created in x, y and z directions. Their strength and phase is measured with sensors attached to the user. Sensor data is then used to calculate the position and orientation of each sensor.

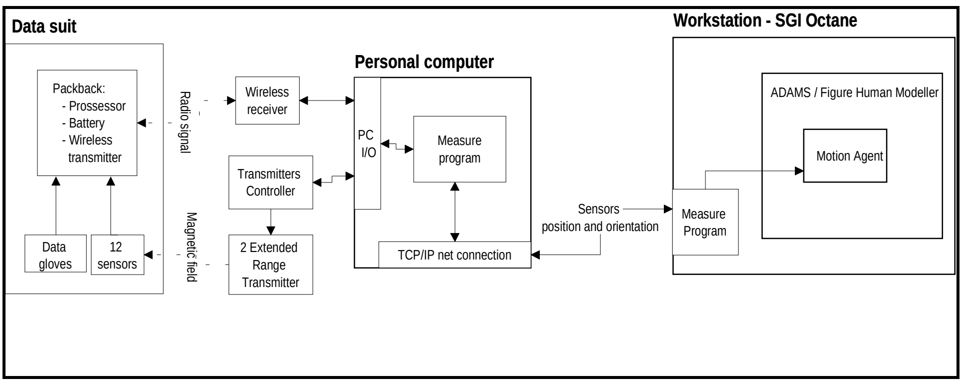

Figure 5. The chart describes the data suit utilised by VTT Automation and the transmission of data to the FIGURE Human Modeller run on an SGI workstation.

Figure 5 describes the operating principle of the motion capture system utilised by VTT Automation. The controller manages the magnetic field created by two transmitters. The operating frequency of the magnetic tracker system can be between 30 and 144 Hz. This research was carried out with the measuring frequency of 100 Hz. The sensors measure the magnetic field and transmit data to the backpack unit, which executes a pre-calculation and transmits the data from sensors and data gloves wirelessly to the computer. The computer's measurement application calculates the position and orientation of the sensors and transmits the data to the measure application in the SGI workstation through a local network. The human model follow in the subject's motions based on the received sensor data. The displacements captured during this simulation will be used for a following direct-dynamics simulation, where the model is driven exclusively with joint torques. From the simulation, joint powers and energies will be examined for this activity.

3. Integration

The integration of simulation and analysis processes is done with the developed external performance data converter (PDC). The converter creates or utilises a configuration profile to data conversion from customer design problem to the digital human model, from digital human model to analysis software and vice versa. This external performance data converter makes it possible to each partner to focus on developing their main issues the design, the simulation and the analysis.

4. Analysis

In a former study (Nilsson *et al*. 1992) methods and procedures for simulation and ergonomic evaluation of work by means of graphical computers and software for modelling, animation and biomechanical evaluation were presented. The biomechanical analysis is done by means of the multibody systems module and results in statically as well as dynamically estimated torques and resultants forces on joints and body segments. The values obtained can be compared with tissue strength data and maximal capacity for force exertion. The lower the values the better, but the time course must also be considered and an integrated value representing the dose of load on each joint calculated. When the loading on one joint must be traded against an other, an optimisation procedure could be used to reach a favourable loading situation provided that a suitable criterion can be formulated. If the physiological effects of the mechanical load are to be analysed, e.g. muscle fatigue and recovery, then the time pattern of the loading must be considered and other models be used for the evaluation. (Nilsson *et al.*, 1992)

Vibration can be sensed in different parts of the body across a very wide range of frequencies, from 0.1–10 000 Hz. However, it is generally agreed that human sensitivity to whole body vibration is greatest around 4–8 Hz in the z (up and down) direction and 1–2 Hz in the x and y directions. ISO 2631 defines the limits of exposure to vibration in both z and y directions (1–80 Hz range) in terms of three criteria: a) preservation of health, exposure level (EL), b) working efficiency, frequency decreased proficiency boundary (FDPB) and c) comfort, reduced comfort boundary (RCB). (Wilson *et al.*, 1995)

4.1 Converter and Ergonomic Analysis

Converters basic idea is the possibility to transfer joint and position values between different human models, and possibility to calculate ergonomic values from these joint values. With Converters help, it's possible to take advantage of best features of each human model. Converter works independently, and it isn't dependent from another software, although position and joint values used as input, have to be predefined type.

Program is used from command line, and it's character based. At startup user selects ergonomic values which he wishes to calculate, and values to be printed to x-axis. Currently RULA, OWAS, WinOWAS and ErgoKan are integrated to the converter. As Figure 6 shows program calculates ergonomic values and prints them to file and to screen.

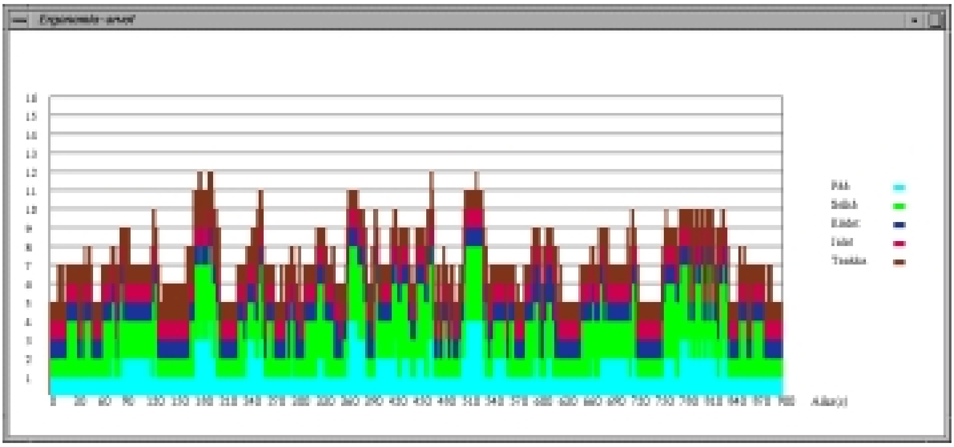

Figure 6. The Ergokan external ergonomic analysis. Ergokan is based on RULA and OWAS ergonomic analyses.

At this stage, program cannot convert joint and position values to another form, because at the time it was programmed there were only one human model at our disposal. In future program should be able to read different joint and position values produced by different software. Type of input file could be determined e.g. with config file, in which user defines angle directions and zero points for each human model.

Figure 7 shows Converters planned functionality. On the left side of the picture are human models and motion capture system which produce position and joint values. On the right side are converted joint values and calculated ergonomic values.

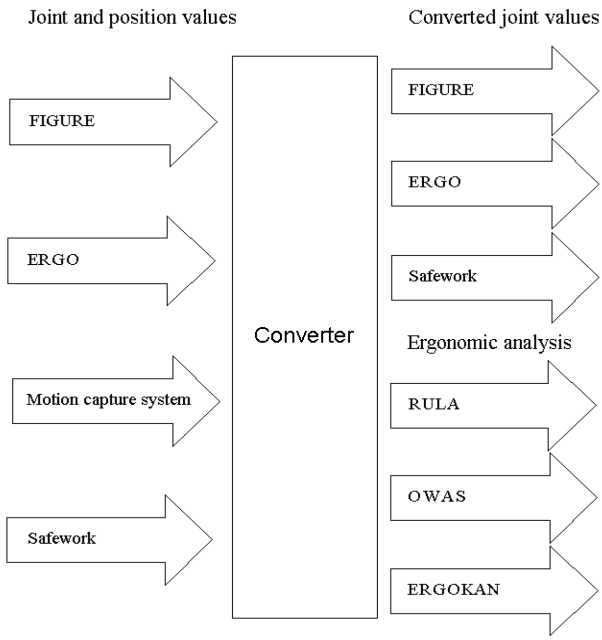

Figure 7. Converter is able to transform digital human model output data into data suitable for ergonomic analysis and other human model.

5. Summary and discussion

The own digital kinetic human model was created and compared to a commercial model. Although having a lot of enhancement needs the model can already now be used to specific human loading simulation and analysis purposes. Also a performance data converter to connect and integrate the customers design problem and the digital human model and the analysis application software were developed and tested. The basic workposture analysis software was implemented based on the RULA, OWAS and Ergokan methods. The integration process utilises the product development portal as easy customer interface to design services via network and the performance data converter, and the analysis software clients. The integration process is only very roughly tested. The portal, converter and analysis software clients need further testing and development efforts.

The greatest benefit in exploiting digital kinetic human models is that the need of physical prototypes and costs decreases because human-machine system's accordance with requirements and legislation can be proved in early design phase. The system can be designed more comfort, ergonomic, safe and efficient. Different options of system can be tested and compared in early design phase, which helps making decisions. The advantage of the data converter and analysis software can be integrated easily to company's tools and design systems. Without digital human models and virtual prototypes interactive performance of human-machine system can not be analysed.

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Virtual manufacturing on the Internet

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Abstract

In this investigation, a prototype system for a virtual manufacturing environment on the Internet was developed. The environment supports product development of roll formed products. The system includes a geometric modeling system and an analytic solver for simulating roll forming. This investigation shows that it is relatively easy to develop virtual manufacturing environments that work on the Internet with minimum effort by using HTML language and utilizing public domain software modules.

1. Introduction

1.1 Background

Development of a new product is connected with process design, process planning, production planning and shop floor control. The product design process needs information from the other processes and also produces data for them. The whole information system is complicated and management of the system is difficult. The quality of the system and processes will affect the quality and price of the product.

The critical part of the product development process is the early stage because most of the product cost (70% by some estimates) is committed during initial phases of the process. The decisions made in the early stage are also important because errors will be costly to repair in the later stages. Investing in the development of the methods and tools to support the design process will make it possible to earn high profits on the investment. One possibility to increase the effectiveness of the design process is to use virtual manufacturing (VM).

VM is an integrated synthetic manufacturing environment, exercised to enhance all levels of decision and control. VM uses product, process and resource models to evaluate the producibility and affordability of new product concepts prior to a commitment to the final product design. VM can support all levels from evaluation of the overall performance of the factory to manufacturability of a component and process parameter optimization.

A VM environment can be built on the Internet. World Wide Web technology facilitates the gentle distribution of product development work in geographically distributed sites. VM technologies distributed over the Internet provides an environment that can be platform independent and an easy to use tool for product development.

1.2 Aim and scope

The aim of this investigation was to develop an application oriented VM environment to work on the Internet. The VM environment was built to support product development of roll formed products.

Roll forming is a process in which a sheet or strip is progressively bent to a desired shape by bending between successive sets of rotating rolls (Figure 1). The process is simulated by using the VTTube program, which is a fast analytical program for calculating strains and roll forces in the roll forming of rectangular tubes. With this program, the user can find optimal roll scheduling to minimizes uneven strains that cause forming defects.

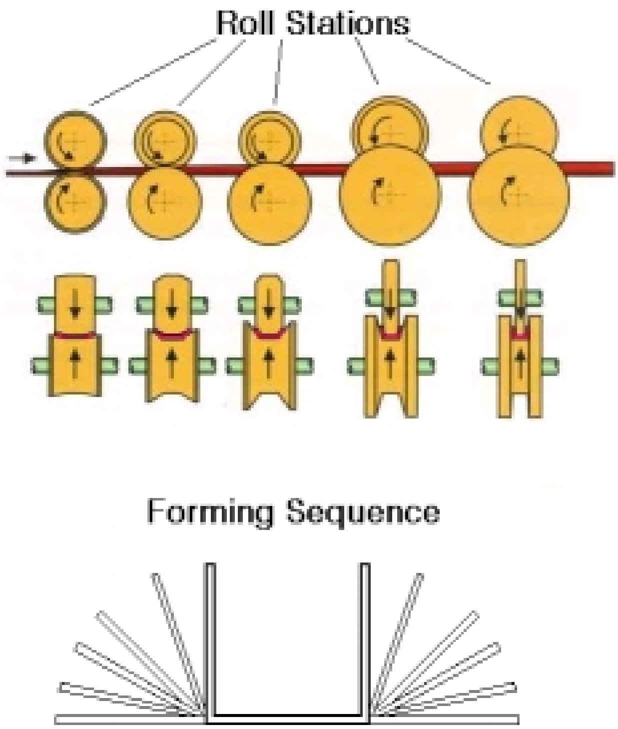

Figure 1. Schematic drawing of a roll forming process.

2. Implementation

The developed VM environment named webVTTube (Figure 2) consists of an HTTPserver (HyperText Transfer Protocol), a graphical user interface (GUI), an analysis program (VTTube), a local CAD system and a STEP interface. The analysis program is implemented as a CGI program (Common Gateway Interface). The HTTP server (Apache) can be run on a server or a workstation (local installation).

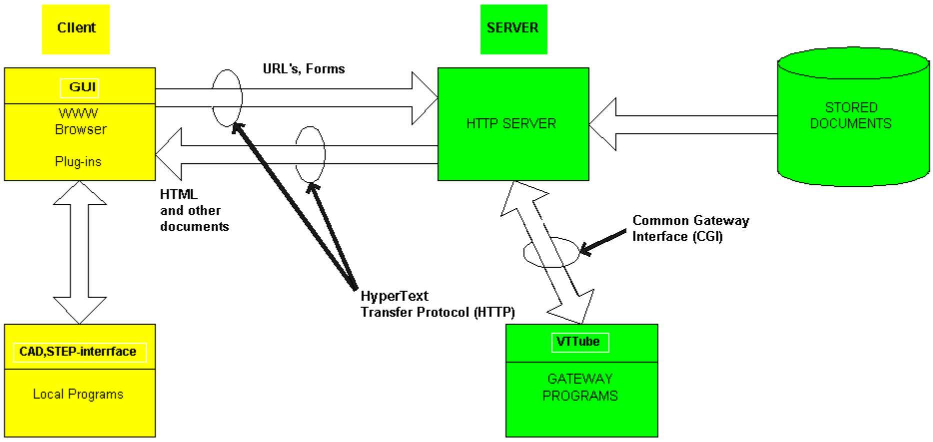

Figure 2. Architecture of the developed VM environment.

The graphical user interface (Figure 3) is programmed using HTML (HyperText Markup Language). The specifications for the roll forming mill and the product can be given manually using this HTML form or the data can be imported from a CAD system via STEP. The STEP file is processed and transferred by the STEP interface into the dynamically created HTML form. The form is sent to the server to be processed by the CGI program.

The CAD interface of the webVTTube was implemented by using the STEP interface (supporting AP203). This interface was programmed in C, using SDAI application programming interface (Standard Data Access Interface).

In the webVTTube environment also the CAD-system communicates with a browser (the CAD-system is Pro/ENGINEER with a Pro/Web.Link, that provides a JavaScript API). The HTML-page serves as an adviser that guide the user through a discrete process for manipulating the parametric model (Figure 4) and for producing a STEP file of it.

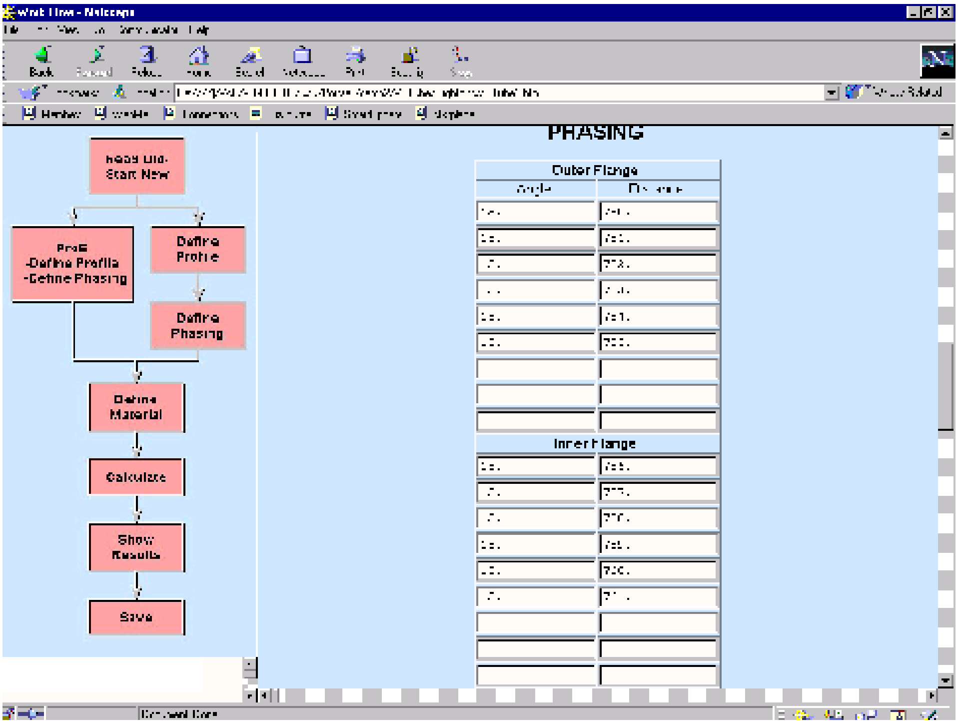

Figure 3. Graphical user interface of the webVTTube. The flowchart serves as the main menu of the program.

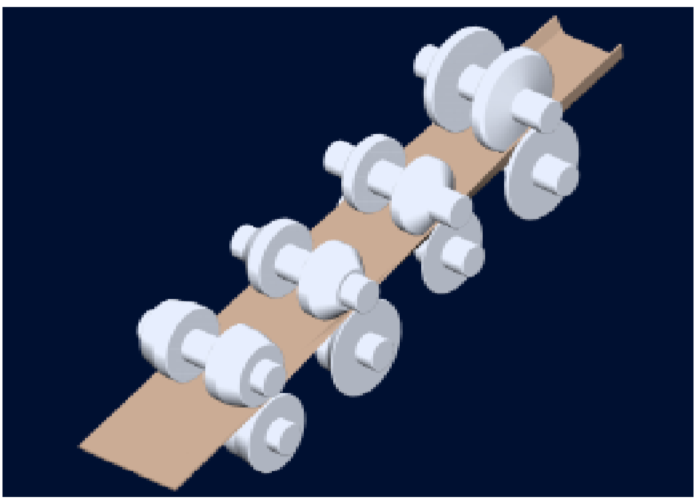

Figure 4. Parametric model of the roll forming mill.

The VTTube program writes the analysis results in VRML format (Virtual Reality Modeling Language), which are visualized in the browser by using a public domain VRML plug-in (Figure 5).

The developed system is included in the VTTpdp product development portal (Sääski & Salonen 2001). VTTpdp provides the user access to other processes that are needed in the product development process.

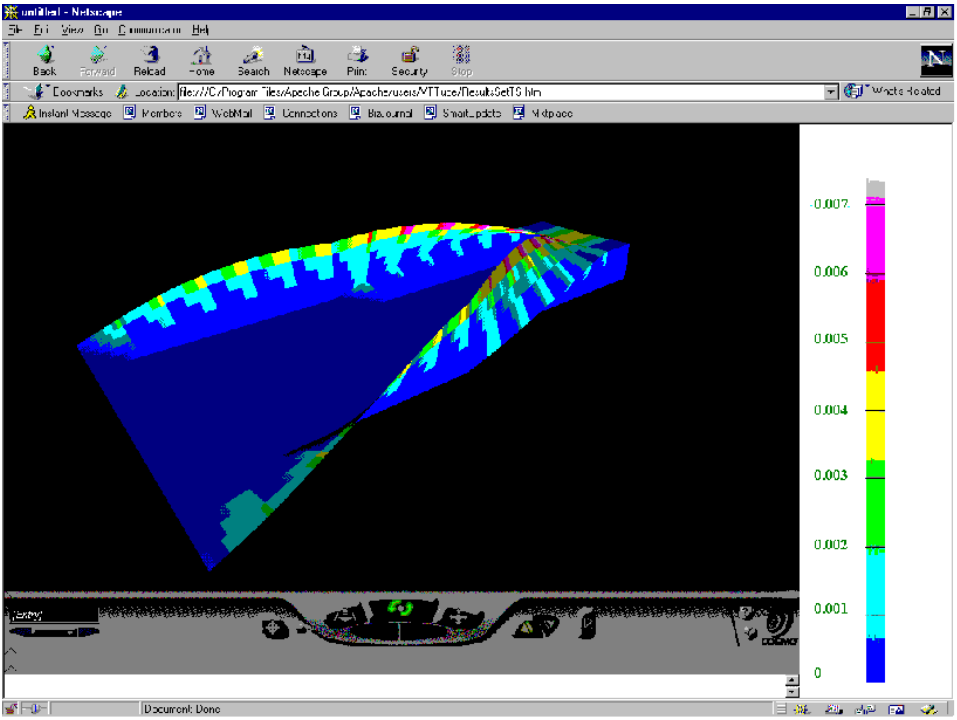

Figure 5. Development of strains in the profile passing subsequent forming rolls. Data represented using VRML and a dynamically created page.

3. Discussion

By means of the webVTTube it is possible to find out the optimal roll scheduling interactively while working on the Internet. The analysis gives an approximate solution, but a more accurate analysis, if needed, can be calculated by FEM.

The investigation shows that the HTML based graphical user interface is suitable for current applications and can be “programmed” with minimum effort using a commercial, easy to use HTML editor.

The VRML standard (VRML97) provides the features needed for the current implementation. Utilization of VRML does not require much effort and it saves resources because a visualization module does not have to be developed: a commercial or a public domain visualization software can be used.

The programming of the STEP interface demands in-depth knowledge of the standard and its features. The people who have experience with this standard and its implementation should carry out the work.

VTTube was implemented as a CGI program. The data transfer part of CGI program generated is based on a public domain code. Because of this, it was easy to implement and does not require in-depth knowledge of the standard. The CGI program works well in the kind of situation where running times are short and there are only some active clients.

Utilization of CORBA (Common Object Request Broker Architecture), Java (or Java3D for visualization) and XML (Extensible Markup Language) could be more appropriate for more advanced applications.

4. Conclusions

In this investigation a virtual manufacturing environment for simulation of roll formed tubes running on the Internet was developed. The analysis program is implemented as a CGI program. The specifications of the roll forming mill and the product can be given manually using HTML-form or the data can be imported from a CAD system via STEP.

The chosen approach with CGI, the dynamically generated HTML pages and the utilization of VRML technology was sufficient for the current implementation. The programming work does not demand in-depth knowledge of different standards and programming languages except in the case of STEP, which demands more expertise from the programmer. For more complicated applications XML, Java or Java3D and CORBA may be more appropriate.

The program system developed is a prototype and after small modification it can be installed on a World Wide Web server to provide a roll forming module for virtual manufacture environments.

Acknowledgements

The basic solver of the webVTTube environment was developed in an on-going 3DFORM research project funded by TEKES (Tekniikan edistämissäätiö; Technology Development Center of Finland), Helsinki University of Technology, VTT Manufacturing Technology, Outokumpu Polarit Oy and Stala Oy. The possibility to use VTTube as a kernel for the solver of the webVTTube is acknowledged.

The help of Mr. Antero Katainen for making the parametric geometry model is greatly appreciated. Mr. Juha Sääski's assistance in programming the STEP interface is also greatly appreciated.

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Virtual production system development in product process

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Abstract

The approach presented in this paper has four elements. It is a SPOT approach: Strategy, Process, Organisation and Tools. The article covers the topics in a time-based strategy, product process and the use of virtual production development tools. Time-to-market is important; speed gives a competitive edge, but should not do so at the expense of quality of the development execution. The Stage-Gate Product Process is one technique for managing new product development in cross-functional teams. The product and production process development should be done in an integrated parallel manner. Production simulation and virtual manufacturing tools are valuable in the design of modern complex production systems. The visualisation of problems improves communication and understanding and leads to better decisions .

1. Introduction

Companies are facing increasing time-to-market pressures, and product cost reduction is needed despite a shrinking product lifetime. Product differentiation is becoming more difficult and multi-disciplinary. There are an increasing number of technology choices. Time-to-market is critical, meaning faster product and production system design and faster ramp-up processes. Product and production development can no longer be sequential but must now be done in parallel.

Production system flexibility is a key factor. Flexible systems are becoming increasingly complex and development of the production system more challenging. Production system design involves a number of interrelated subjects such as tooling strategy, material-handling system, system size and process flow configuration. Production process design is a critical area. Material handling is another area that deserves intensive study. Although this function does not add value to the product, it facilitates the production process flow. The final production step is the assembly process and it is more than putting parts together. Assembly is the activity in which all the upstream processes of design, engineering, manufacturing, and logistics are brought together to create an object that performs a function. In the product development from idea to launch the development team must design a product, processes, production resources and all the other processes needed from order delivery to final customer, service, and finally recycling.

Production simulation and other virtual manufacturing tools are valuable in shortening the design steps and evaluating complex systems. A virtual production system also shorten the production ramp-up time, because the operators know the planned system better and can study the parameters and features of the new system before anything is installed on the factory floor.

The real value of Modelling and Simulation (M&S) tools is their ability to capture and represent knowledge to make more reliable predictions – predictions for driving product design, process design and execution, and management of the enterprise. Product and process development has historically been accomplished through testing designs to see how well they work, then modifying the design and testing it again. This test/evaluation/modification phase consumes a vastly disproportionate share of the time and cost required to move a product from concept to delivery. Engineering change order costs can be significantly reduced by investing more in the initial design, using M&S tools to optimise products and processes in the virtual realm before committing resources to physical production. (IMTI 1999)

2. Time-based strategy

A faster to-market time is necessary but should not be at the expense of quality of the development process execution. Speed offers a competitive edge; there is less likelihood that the market or competitive situation might change, and it means a quicker realisation of profits.

The components of a time-based strategy are listed in Table 1.

Table 1. Components of a time-based strategy (Charney 1990).

Planning and evaluation	Goal setting
Simultaneous engineering	Reduced bureaucracy
World class manufacturing	Use of computers in design and manufacture

Development teams should be multifunctional, doing parallel processing with the aim of "Do it right the first time". The later the engineering change is done in the development process, the more expensive it will be, as shown in Table 2.

Table 2. Typical cost of design change to a major electronics product (Charney 1990).

When changes are made	Costs
During design	$ 1,000
During design testing	$10,000
During process planning	$100,000
During test production	$1,000,000
During final production	$10,000,000

The idea is to improve effectiveness in 'early design' where costs are low and leverage is high. Virtual production development and 3D visualisation tools are valuable here, as well as virtual product prototyping.

3. Product Process

Integrated Product and Process Development (IPPD) is an expansion of concurrent engineering utilising a systematic approach to the integrated, concurrent development of a product and its associated manufacturing and sustainment processes to satisfy customer needs. IPPD is a management process that integrates all activities from product concept through production/field support, using a multi-functional team, to simultaneously optimise the product and its manufacturing and sustainment processes to meet cost and performance objectives.

New product development begins with an idea and ends with the launch of a new product. The steps between these points can be viewed as a systematic process. The Stage-Gate Process is presented here according to Coopers (1993).

3.1 Stage-Gate Process

An overview of the Stage-Gate Process appears in Figure 1. The objectives of the Stage-Gate Process are to improve the probability of success, reduce the time to market, optimise available assets, and reduce the cost of design. It is a best-practice prescription for new product management that includes a consistent commitment of the necessary resources along with a strategy consistent with the development goals.

The Stage-Gate Process is a technique for managing new product development by breaking the process into a series of pre-determined stages consisting of a set of prescribed multi-functional and parallel activities. The stages are discrete and identifiable, typically four, five or six in number.

In the entrance of each stage is a gate or Go/Kill decision point. The purpose of each gate is to review the deliverables from the previous stage and plan the continued development of the project. The gate also provides an opportunity for checking the quality of the progress. It allows all of the team members to prioritise the upcoming tasks. One important aspect of each gate is the opportunity to determine the value of continuing the project. This helps to contain projects that tend to take on a life of their own without a clear vision for the end result.

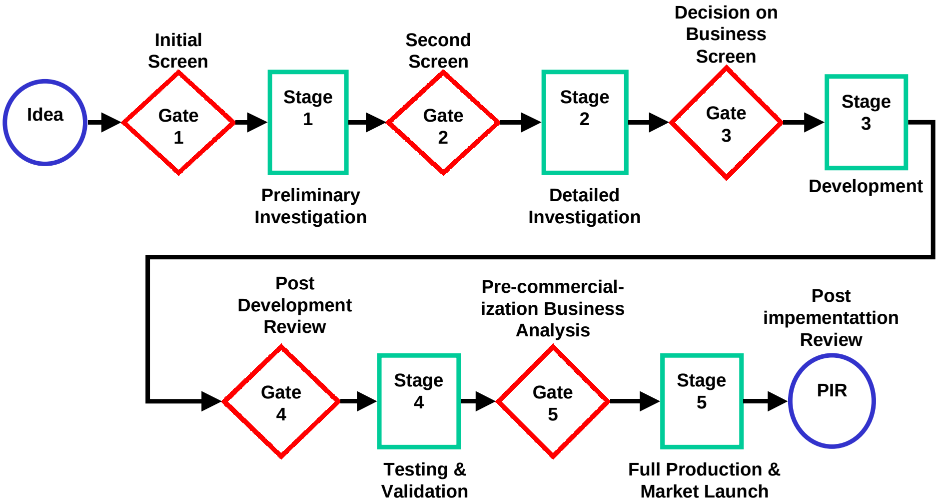


Figure 1. Overview of the Generic Stage-Gate Process (Coopers 1993).

Achieving cross-functional integration changes what the functions do, when they do it, and how they get the work done. Table 3 examines three major functions involved in development – engineering (with a focus on product design), marketing (including marketing research and sales) and manufacture (including process development, manufacturing engineering and plant operations). The roles of the other functions not listed here are important as well.

There are two different modes of production process development:

1. Product centric planning, no modifications to the product, just system design.
2. Process centric planning, DFA, DFM approach, improvements to products for easy manufacturing and assembly.

The IPPD development team should combine both of these. This creates a need for problem solving and conflict resolution methods. One solution is the use of visualisation and simulation tools.

Table 3. Task of engineering, marketing and manufacturing and key results and decisions, modified from Wheelright and Clark (1992).

Functio-nal Activities	Phases of Development, stages					
	Concept Evaluation	Planning & Specification	Detailed Design and Development		Test & Evaluation	Product Release
			Phase I	Phase II		
Engineer-ing	Propose new technologies; develop product ideas; build models; conduct simulations	Choose components and interact with suppliers; build early system prototypes; define product architecture	Do detailed design of product and interact with process; build full-scale prototypes; conduct prototype testing	Refine details of product design; participate in building second-phase prototypes	Evaluate and test pilot units; solve problems	Evaluate field experience with product
Marketing	Provide market-based input; propose and investigate product concepts	Define target customer's parameters; develop estimates on sales and margins; conduct early interaction with customer	Conduct customer test of prototypes; participate in prototype evaluation	Conduct second-phase customer tests; evaluate prototypes; plan marketing rollout; establish distribution plan	Prepare for market rollout; train sales force and field service personnel; prepare order entry/process system	Fill distribution channel; sell and promote; interact with key customer
Manufac-turing	Propose and investigate process concepts	Develop cost estimates; define process architecture; conduct process simulation; validate suppliers	Do detailed design of process; design and develop tooling and equipment; participate in building full-scale prototypes	Test and try out tooling and equipment; build second-phase prototypes; install equipment and bring up new procedures	Build pilot units in commercial process; refine process based on pilot experience; train personnel and verify supply channel	Ramp up plant to volume targets; meet targets for quality, yield, and cost
Gate	Gate 1	Gate 2	Gate 3		Gate 4	Gate 5
Key results	Concept for product and process defined	Establish product and process architecture Define program parameters	Build and test complete prototype Verify product design	Build and refine 2nd phase prototype Verify process tools and design	Produce pilot units Operate and test complete commercial system	Ramp up to volume production. Meet initial commercial objectives
Key Decision	Program Release	Specification Release	Design Release		Manufactur-ing Release	Sales Release

4. Modelling, simulation, and design

Modelling and Simulation (M&S) are emerging as key technologies to support manufacturing in the 21st century, and no other technology offers more potential than M&S for improving products, perfecting processes, reducing design-to-manufacturing cycle time, and reducing product realisation costs. Although specialists currently use M&S tools on a case-specific basis to help design complex products and processes, use of M&S tools other than basic computer-aided design/engineering (CAD/CAE) applications is largely limited to solving specialised design and production problems (IMTI 1999).

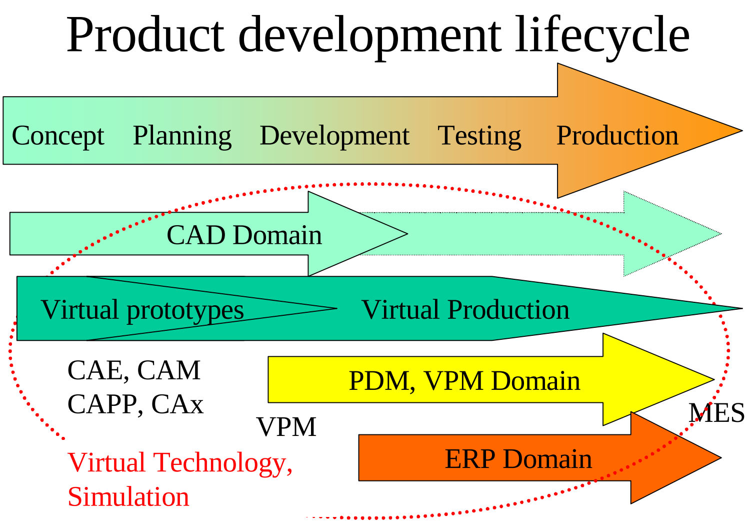
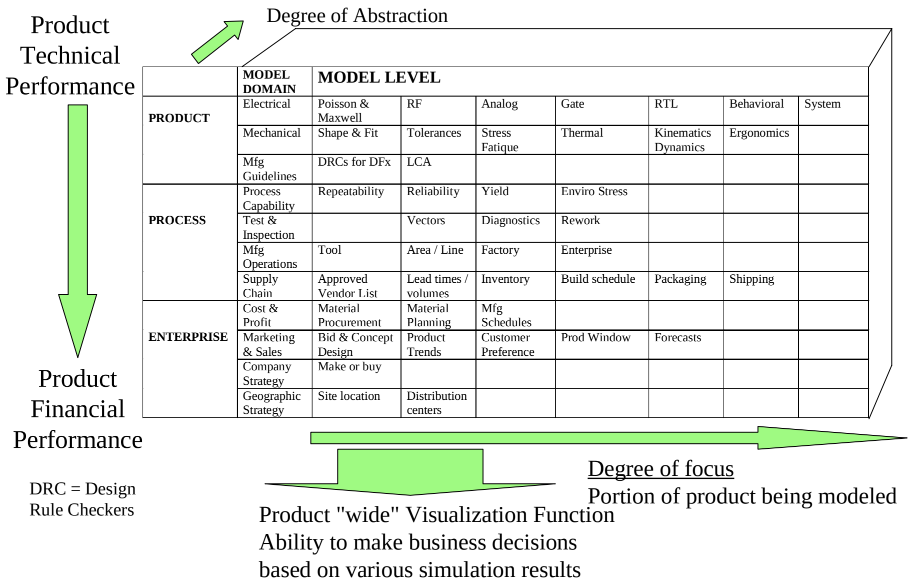


Figure 2. Different IT (Information Technology) tools in product life cycle.

Virtual prototype engineering methodology consisting of three modelling and simulation realms (NEMI 1998):

1. Product Modelling & Simulation – In which the design intent is expressed and desired functionality is assessed.
2. Process Modelling & Simulation – In which the fabrication is expressed and the ability to manufacture is assessed.
3. Enterprise Modelling & Simulation – In which the extended enterprise, e.g. supplier base, distribution, logistics, etc. is expressed, and decision hypotheses, are assessed.

Developing a product and moving it from concept to successful market introduction involves making many business decisions. The simulation matrix in Figure 3 attempts to capture the scope of the modelling and simulation activities that help resolve the risks and tradeoffs associated with these decisions. Each cell in the matrix represents modelling and simulation activities that may be occurring in parallel and need to share and exchange information with one another. Each cell also has a "depth" dimension, noting that there may be multiple tools or models representing various levels of abstraction. Clearly modelling and simulation permeate the entire enterprise (NEMI 1998).



	MODEL DOMAIN	MODEL LEVEL							
PRODUCT	Electrical	Poisson & Maxwell	RF	Analog	Gate	RTL	Behavioral	System
	Mechanical	Shape & Fit	Tolerances	Stress Fatique	Thermal	Kinematics Dynamics	Ergonomics	
	Mfg Guidelines	DRCs for DFx	LCA					
PROCESS	Process Capability	Repeatability	Reliability	Yield	Enviro Stress			
	Test & Inspection		Vectors	Diagnostics	Rework			
	Mfg Operations	Tool	Area / Line	Factory	Enterprise			
	Supply Chain	Approved Vendor List	Lead times / volumes	Inventory	Build schedule	Packaging	Shipping	
ENTERPRISE	Cost & Profit	Material Procurement	Material Planning	Mfg Schedules				
	Marketing & Sales	Bid & Concept Design	Product Trends	Customer Preference	Prod Window	Forecasts		
	Company Strategy	Make or buy						
	Geographic Strategy	Site location	Distribution centers					

Figure 3. Scope of modelling and simulation activity, modified from NEMI 1998.

There are many challenges for product and production development engineers:

1. Less time for process planning and system design
– Shorter product lifetime, more product models and variations
– Increased process complexity, and lower costs while increasing quality
– First-to-Market versus Time-to-Market versus Time-to-Customer

2. Different computer aided tools are needed in the design process
– Different user interface for each tool: high training and maintenance costs
– Little or no data compatibility: difficult to transfer results between tools

3. Multiple simulation environments
– Inefficient to iteration between different tools
– UNIX versus Windows and CAD-embedded versus stand-alone.

There are a large number of tools; the level of details is varying as well as the scope. These are outlined in Tables 4 and 5 and Figure 4.

Table 4. Use of production simulation and analysis tools in different manufacturing domains.

Manufacturing domain	Target	Type of tool
Enterprise	Supply Chain Management Logistics, Flow Analysis and Optimisation	Optimisation Discrete Event Simulation Other Simulators
Plant or factory	Scheduling and Logistics Flow Analysis and Optimisation Layout planning	Optimisation Discrete Event Simulation Other Simulators
Line or system	Throughput, Capacity WIP, Costs Flow Analysis and Optimisation	Discrete Event Simulation Queuing theory Optimisation
Work cells	Feasibility Detailed Process Planning Cell Layout Optimisation Ergonomics	Process Simulation Robots and man models
Individual operations	Cycle Time, assembly sequence Tool and jig design Yield Prediction Product and Process Tolerance Stack Up	Process Simulation Digital Mock-Up Tolerance Analysis
Product concept	Design Rule Checkers Design for Assembly, Design for Manufacturing, Design for Environment, Recycling	Digital Mock-Up DFx-tools, Cax-tools LCA, DFA,DFE, DFR, etc.

Table 5. Modelling and simulation tools

Application of Simulation and Modelling	How, why, what	Aims and drivers
3D CAD/CAE tools Functional Virtual Prototype Digital Mock-Up	Virtual Prototypes of the product is used to test and verify product functions or even test performance of the product.	Improve communication in concurrent engineering teams Visualisation and learning Time-to-Market/Quality
CAM/CAPP CAME/CAPE tools Virtual Assembly Virtual Process	Production modules and product are compared against Design for assembly and manufacturing requirements. Design Rule Checkers	Design for Assembly Design for Manufacturing Verify the process and process documentation Time-to-Market/Quality
Virtual Manufacturing Digital Plant	Production line concepts and product modules are simulated. Decision aid for managers, make or buy. Capacity planning.	Production system performance, production capacity, utilisation etc. Design for fast ramp-up. Time-to-Customer
Virtual Logistics	The supply chain is tested and simulated. Capacity and logistics planning of production network. Supply Chain Management.	Design for Logistics Design for fast sales and penetration Time-to-Customer
Virtual Enterprise	Both delivery and supply chains including information chains with enterprise partners are simulated.	Design for fast sales and penetration Time-to-Customer

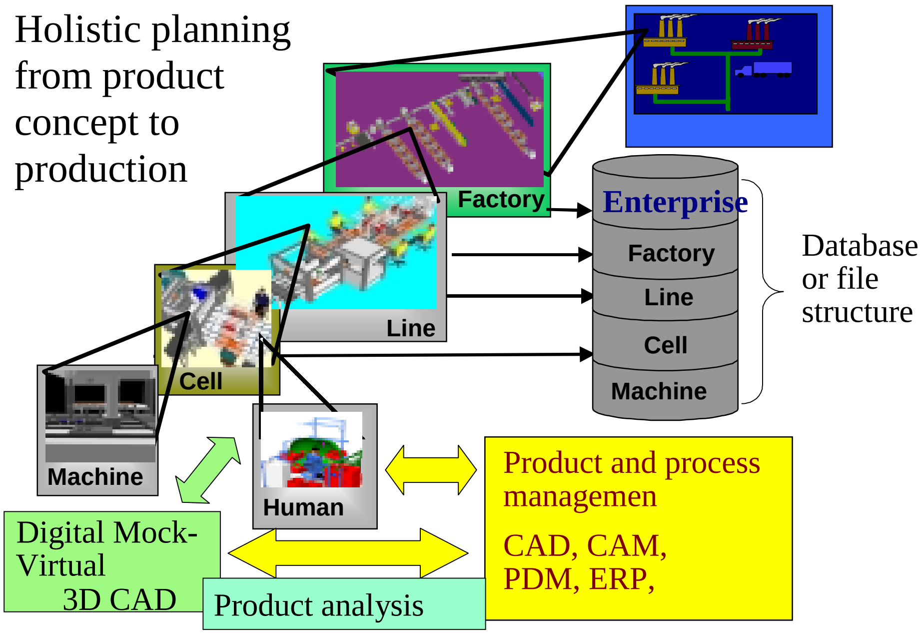


Figure 4. Holistic planning starts from the product.

4.1 Virtual production development tools in the Stage-Gate Process

The development at different stages of the product process is iterative. After each decision gate the engineers pass to a more detailed level, from idea to concept, specification and development. The use of virtual development tools at different stages is summarised in Table 6.

Table 6. Stage-Gate Product Process and virtual production development.

Stage	Virtual tools, technique and use
Stage 1. Concept Evaluation Aim: Concept for product and process defined Key deliverable: Program Release	Functional flow-charts. Draft 3D visualisation, list of product components, knowledge of existing and new submodels. Manufacturing process, estimates of manufacturing volumes and costs
Stage 2. Planning & Specification Aim: Establish product and process architecture Define program parameters Key deliverable: Specification Release, Program plan	3D CAD, CAM, CAE, CAPP, Digital Mock-Up, Functional virtual Prototype. Virtual process and manufacture. Virtual logistics. Requirements for tool and manufacturing process design. Requirements for product design
Stage 3. Detailed Design and Development Aim: Build and test complete prototype Verify product design. Verify process tools and design Key deliverable: Design Release	Refined virtual prototypes, and first real prototype. Training of service people with simulation models. Training of manufacturing operators with simulation models. Detailed virtual functional prototype = Design Approval Detailed product and virtual manufacturing process model = Process Approval
Stage 4. Test & Evaluation Aim: Produce pilot units, operate and test complete commercial system Key deliverable: Manufacturing Release	Virtual production Ramp up. Production Planning & Scheduling. Customer training with simulation models.
Stage 5. Product Release Aim: Ramp up to volume production. Meet initial commercial objectives Key deliverable: Sales release	Operation planning using simulation. Product and production problem solving using simulation models

4.2 Product, Process and Resource (PPR) master models

The current development trend within the development tools is towards PPR models, a Product-Process-Resource database with internet browser interface. This boosts enterprise-wide efficiency through a "Process Centric" shared view of the Product, Process and Resource (PPR) master models. With these tools, M.B.O.M. (Manufacturing Bill of Material), process plans and corporate process knowledge for best practices, and BOP (Bill of Process), are captured for reuse to eliminate costly mistakes, provide quality through a consistent process, and speed product launch. In addition to validating the process, these tools can generate product state and process demonstration. It is possible to perform trade studies of various manufacturing alternatives, and trade-offs between product design and manufacturing design.

The pioneers in this field are Tecnomatix (2000) and Delmia (2000). They offer programs that tie together the PPR databases used to support process creation, validation, simulation, and updates to the PPR models at any stage of the development cycle. An example of such a tool is shown in Figure 5.

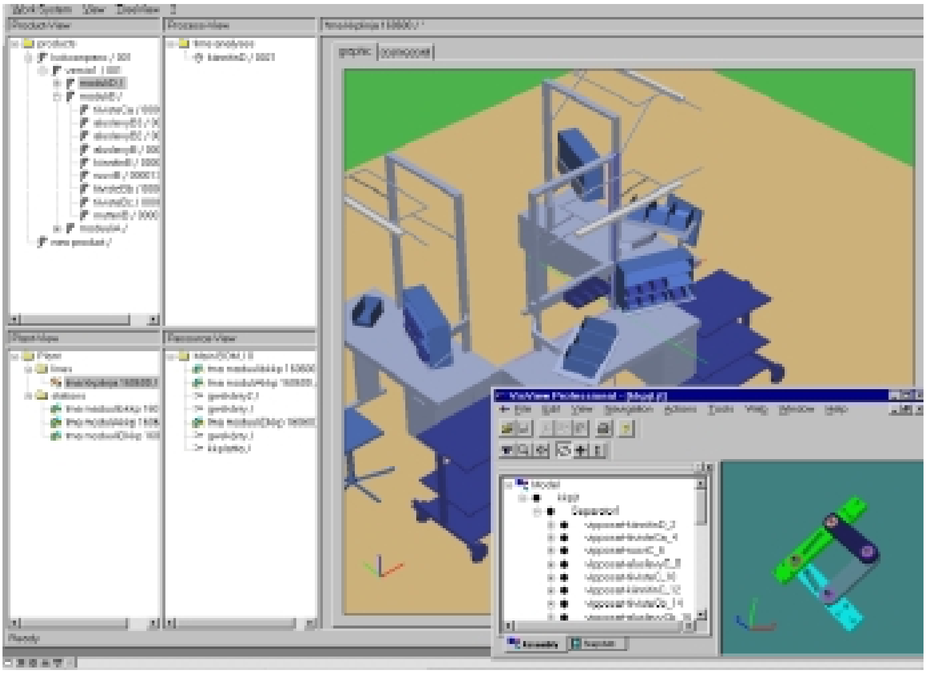


Figure 5. Product-Process-Resource browser, special interface for ErgoPlan planning tool.

4.3 Meeting place for cross-functional teams

Being able to present the information in an effective manner results in an efficient transfer of knowledge. Visualisation and simulation of the problem is the key factor. Cross-functional team members can better understand the problem and its effects. Thus visualisation promotes a efficient decision-making process.

The Virtual Product, Process and Production Development Centre (VIP Centre) is a high-tech conference room at VTT Manufacturing Technology. The aim is to improve the quality of decisions and speed up the design process. The VIP Centre has computer tools and other audio-visual equipment to review product, process and production system models on multiple video screens. The VIP

Centre is a meeting place for a cross-functional forum, even when some participants are only connected electronically (video conference and web connections). The VIP Centre also serves as a training venue for users and as a presentations room for managers.

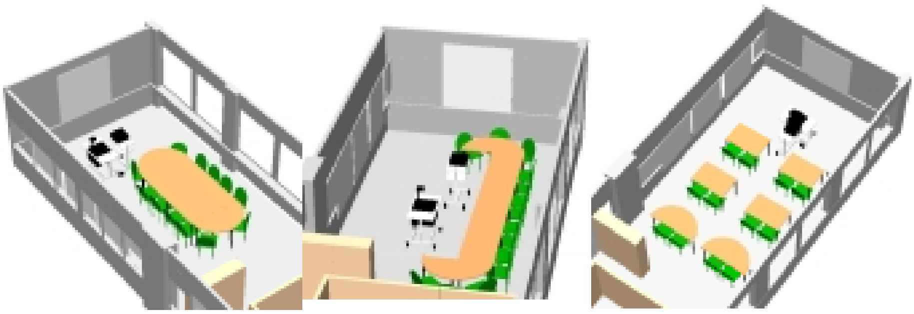


Figure 6. VIPP-Centre at VTT Manufacturing Technology has easy to modify layout.

A meeting place with visualisation tools is important for problem solving. Other important areas are development review and project management tools. For example, a project portal is a web site accessible by all team members who wish to review the minutes and decisions of past meetings as well as the latest developments. The use of internet/intranet supports virtual development teams, regardless of geographic separation.

5. Discussion and conclusion

Time is a competitive weapon. The product process needs efficient management methods. A State-Gate Process and integrated product and process development teams are possible solutions. The Stage-Gate Process and integrated product and process development have several advantages:

- Brings discipline to a sometimes chaotic process
- Focuses attention on quality of execution
- Speeds up the process because it is cross-functional
- Ensures a complete process – no critical steps are omitted.

The ability to increase the efficiency of processes primarily depends on possessing an understanding of how they function. When participating in continual changing projects, we should work according to a concept based on a few simple principles and axioms.

- All development is a question of optimisation, but not sub-optimisation.
- As many activities as possible should be carried out parallel to each other.
- If the actions of one person are likely to affect the ongoing work of a colleague, the colleague should be notified immediately.

Thus the keys to successfully conducting efficient product and production process development are flexibility in working methods and tools, and excellent communication. The modelling and simulation tools help bring good decisions to early development phases.

Acknowledgements

The authors wish to thank VTT Manufacturing Technology for their funding of the work.

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Advantages and problems of CAVE-visualisation for design purposes

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Abstract

VTT Manufacturing technology has been developing accomplished simulations where virtual reality technology has been used. These simulations have been customised according to the needs of users and available hardware. Growing needs are emerging for high quality visualisation with possibilities for the viewer to immerse in the virtual environment. A pre-feasibility study was performed, which aimed to determine advantages and problems involved with visualisation in CAVE-type virtual room. The research was carried out by testing several models in the Helsinki University of Technology Cave-type virtual room installation. Special interest was focused to the compliance of models, the usability of simulations and the stereoscopic and immersive impressions achieved in the virtual room. The results, even gathered mainly in a one-wall-virtual room, showed the advantages specially visualising large interiors like indoor promenades. The problems pointed out the importance of model construction technique to ensure the compliance.

1. Introduction

A virtual room is a spacially immersive display (SID) which extends virtual model displays to surround the user with multiple screens. A virtual room was first developed in 1993 by the University of Illinois, where it was named as the CAVE. Now the CAVE is a registered trademark of the University of Illinois Board of Trustees. CAVE is an acronym for the CAVE Automatic Virtual Environment. It is a room-sized advanced visualisation tool that combines high-resolution, stereoscopic projection and 3-D computer graphics to create the illusion of complete sense of presence in a virtual environment. The CAVE was the first virtual reality technology in the world to allow multiple users to immerse themselves fully in the same virtual environment at the same time. At the moment several CAVE-type virtual rooms are installed around the world in universities and commercial companies. An essential feature to create immersion is the 3D impression achieved by stereoscopic projection of images.

Multi-wall and floor projection is said to be ideal for "inside looking out" reviews. That is why CAVE-type visualisation was also thought to give advantages to virtual prototyping in the case of ship interior and vehicle design. Because there was not much experience of these opportunities, it was decided to investigate the subject using some models developed in the research program and the nearest virtual room installation in Helsinki University of Technology.

2. Virtual room at Helsinki University of Technology

The CAVE-type virtual room at Helsinki University of Technology is called the HUTCAVE. It is a rear-projection based virtual reality system, where users are surrounded by 3 meters wide and high screens. The stereoscopic images are reflected into these screens with projectors and users are viewing these images with stereo shutter glasses. In addition to shutter glasses one user is equipped with a six degrees of freedom head tracking device, which produces location information, needed for computing of correct stereoscopic perspectives. As a result of tracking user can move around the stereoscopic three-dimensional object which he or she sees through stereoglasses. The user with head tracking device is also equipped other tracked sensors which are used to provide interaction with the virtual environment.

The implementation of the HUTCAVE will have three walls and the floor, although of which only one wall was in active use during the project tests. The visualisation computer is SGI Onyx2 with Infinite Reality2 graphics pipeline, which drives Barco 1209 projector. The shutter glasses and emitters are made by Stereographics and the tracking system used is Motionstar from Ascension Technologies. The interaction devices used are either experimental in-house-made devices or commercial ones e.g. radio mouse manufactured by Logitech.

The HUTCAVE has also 3D audio system capable of producing moving sound sources into three-dimensional space. The sound system is built over Linux-PC with ADAT I/O driving D/A converters connected into 15 loudspeakers.

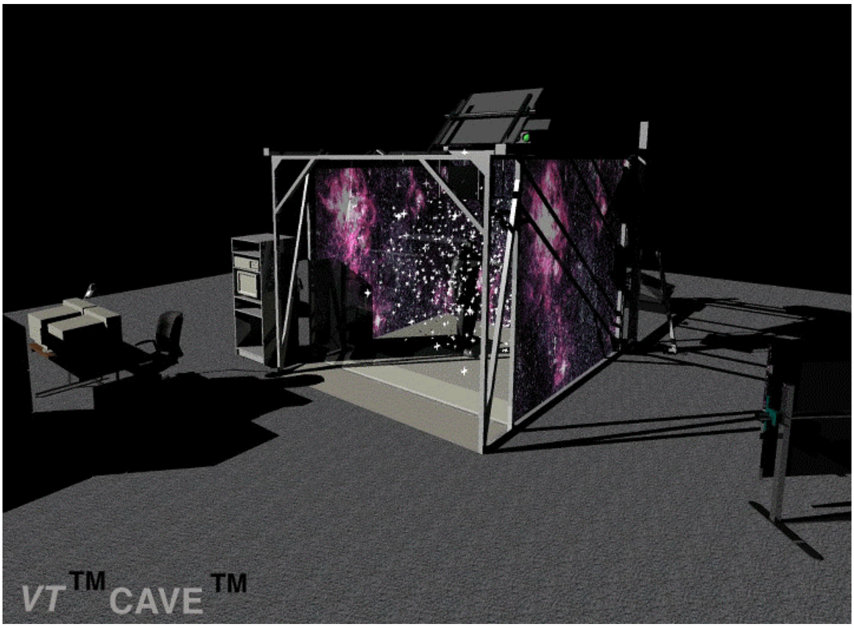

Figure 1. Typical CAVE-type virtual room. Notice the floor projection is from above.

3. Test program

The aim of this project aimed to determine the compatibility between the programs used in VTT modelling & simulation and HUT virtual room visualisation. The project also was the first step to applications where customer simulations could be brought to CAVE-type environment.

In practical level moving geometries from one platform to another is known to work quite well using common data exchange formats like DXF or IGES, but for example moving textures encounters problems even programs are mentioned to support for example virtual modelling language (VRML).

The first problems that can be encountered when moving 3D CAD models from PC world to the CAVE-type environment. These include:

- different model formats
- the effect of size of models to usability
- model applicability to stereoscopic viewing.

Some commercial converter programs can, however, solve these transformation problems. The project was started by evaluating what kind of conversions is required and what converters are available in the commercial market.

During the tests several 3D-models made by VTT were tested in the virtual room of Helsinki University of Technology called HUTCAVE. When the models were successfully moved to the virtual room environment, the stereoscopic impression and immersion could be evaluated.

3.1 Test models

The models for tests were selected so that they represent different kind of spaces that are typical to the customers of VTT Manufacturing technology, Maritime and mechanical engineering department. They included:

- various ship models
  - ship bridges
  - passenger cabins
  - deck spaces of passenger vessels
  - the Promenade space of Silja Serenade
- tractor model
  - tractor as a whole
  - tractor driver cabin.

Figure 2. Ship passenger cabin visualised in the HUTCAVE.

Figure 3. Silja Serenade Promenade model visualised in the HUTCAVE.

3.2 File formats

Iris Performer was used as the visualisation software. In principle it can read several different file formats, but in practise some problems may appear when showing the models in the HUTCAVE. Converting textures, polygon transparency and vertex-normals may cause flaws and imperfections. Based on the CAD software in use especially at VTT and ship and automotive industry, the following file formats were moved or converted to HUTCAVE.

– Catia products and parts, AutoCad dwg and dxf, 3DSMax max and 3ds and VRML.

At the same time also a converter program Okino PolyTrans was evaluated. Without Polytrans the virtual room visualisation software supports only some formats. That is why the transformation has to be done in PC environment. Converters like Polytrans, which in this case was used as a plug-in to 3DStudio Max quite easily, transform the model to Open Flight (flt), which is preferred by virtual room software (Iris Performer).

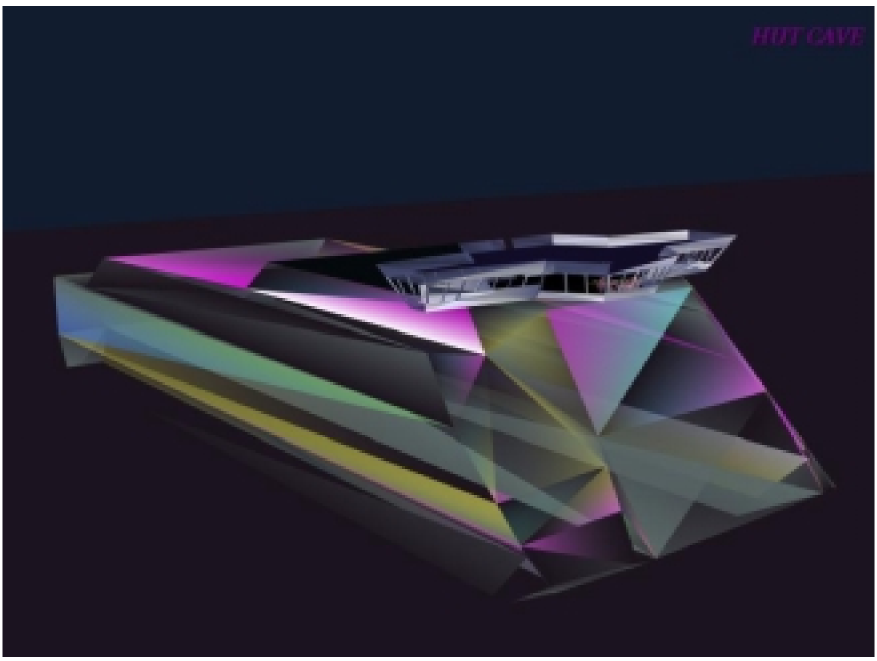

Figure 4. An example of problems encountered due to wrong direction of polygon normals.

3.3 Test results

- Iris Performer itself without converter could read 3ds models without defects and also some vrml-models.
- However the best result was achieved using PolyTrans-converter to transform models to Open Flight (flt)-format.
- The tests showed that CAVE-type visualisation should be taken into consideration when constructing the model. For example the number of polygons, the direction of polygon normals, bothsides-flag, size of textures and their format are critical to the reproducibility of models.
- It should be noted that many problems are due to IRIS-Performer visualisation program used in the HUTCAVE.
- Most of the tests were performed during the period when the HUTCAVE was under construction and only one wall could be used for stereoscopic viewing. That is why the research of the immersion was quite poor.
- The methods to move around in the virtual environment using Stereofly-program and a radio mouse was difficult and required experience.
- The best stereo impression was achieved in large but closed spaces like the Promenade of Silja Serenade
- Increasing the immersion effect by environmental voices was not yet tested.

3.4 Recommendations for further tests

Because the virtual rooms used in the tests were not complete, namely only one wall for projection was available, the immersion effects could not be observed. The research is continuing to test the models in two different virtual rooms with 2–4 walls to observe immersion.

For these tests the models have been optimised by reducing the number of polygons and by improving the details of important areas. The ship model has been constructed to make a virtual environment were moving around will be possible and fluent. The areas, which are not modelled, are closed so that the viewer cannot get lost outside the environment.

To make the use of the virtual room more efficient the models will be checked first by rendering them on monitor screen stereoscopically and viewed with shutterglases. By this method also functioning models and simulations can be visualised and taken to virtual room environment later. For example tractor model moving over terrain or ship in waves could be visualised. Also "walkthrough"-paths can be planned in advance in PC environment to find out the interesting viewing positions and angles for virtual room visualisation.

As future areas of research it is suggested that PC simulators be connected to virtual room visualisation. This would require to determine networking of PC and Unix environments in a way there interface and part of simulations are in PC and visualisation and part of simulation – for example collision detection – are in virtual room visualisation hardware.

For the immersion sound effects make an important part. Pre-recorded sound files or sound generation could be incorporated to the simulations and presented in virtual room environment. These sounds could include environment sounds, collision sounds as well as engine and equipment sounds.

There are several ways to realise simulations in virtual room environment. For example:

- animations included in vrml-model
- simulations using WTK to manage visualisation
- stand alone simulations/simulators connected to virtual room visualisation.

4. Discussion

The use of virtual prototyping is quickly increasing in all phases of product development from visual mock-ups to production planning. Visualisation makes a remarkable part of all virtual prototyping applications. New methods like visualisation in a CAVE-type virtual room can extend the possibilities to new dimensions and means for collaborative work. A virtual room offers high quality visuals and a new type of user immersion to observe the planned design. This usually means that some sort of hardware must also be integrated. However, taking simulations to visualised in virtual room is not straightforward. To fulfil the requirement of a real-time interactive simulation effective networking between the simulation and visualisation hardware is needed. Functional simulations also require suitable interaction and navigation methods in the environment. In this process not only technical performance but also human behaviour must be taken into consideration.

The CAVE-type visualisation will undoubtedly offer fascinating possibilities to demonstrate new designs. Architectural interior designs can be presented to customers and decision-makers. Engineering design can be illustrated and debated collaboratively in virtual room meetings. The CAVE-type virtual room is an expensive installation that requires cost-effective software applications to be developed to encourage their usage in virtual prototyping.

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Virtual prototyping
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Abstract

This publication documents the papers to be presented at the Virtual prototyping seminar on 1.2.2001 at Otaniemi Espoo. The seminar presents the main results of Virtual prototyping research programme (1998–2000) of the Technical Research Centre of Finland VTT.

The research programme included two main research projects. In the research project 'Integrated simulation based design', the aim was to develop an integrated simulation based design system which combines the design, manufacturing and use of a product in virtual environment.

The goal of 'Virtual Integrated Product and Production Development'-research project was creation of integrated product process to accelerate the whole development process from concept to production launch using virtual production tools currently available at VTT Manufacturing Technology.

Keywords

products, prototypes, virtual design, virtual prototyping, computerized simulation, product development, manufacturing planning, modelling

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